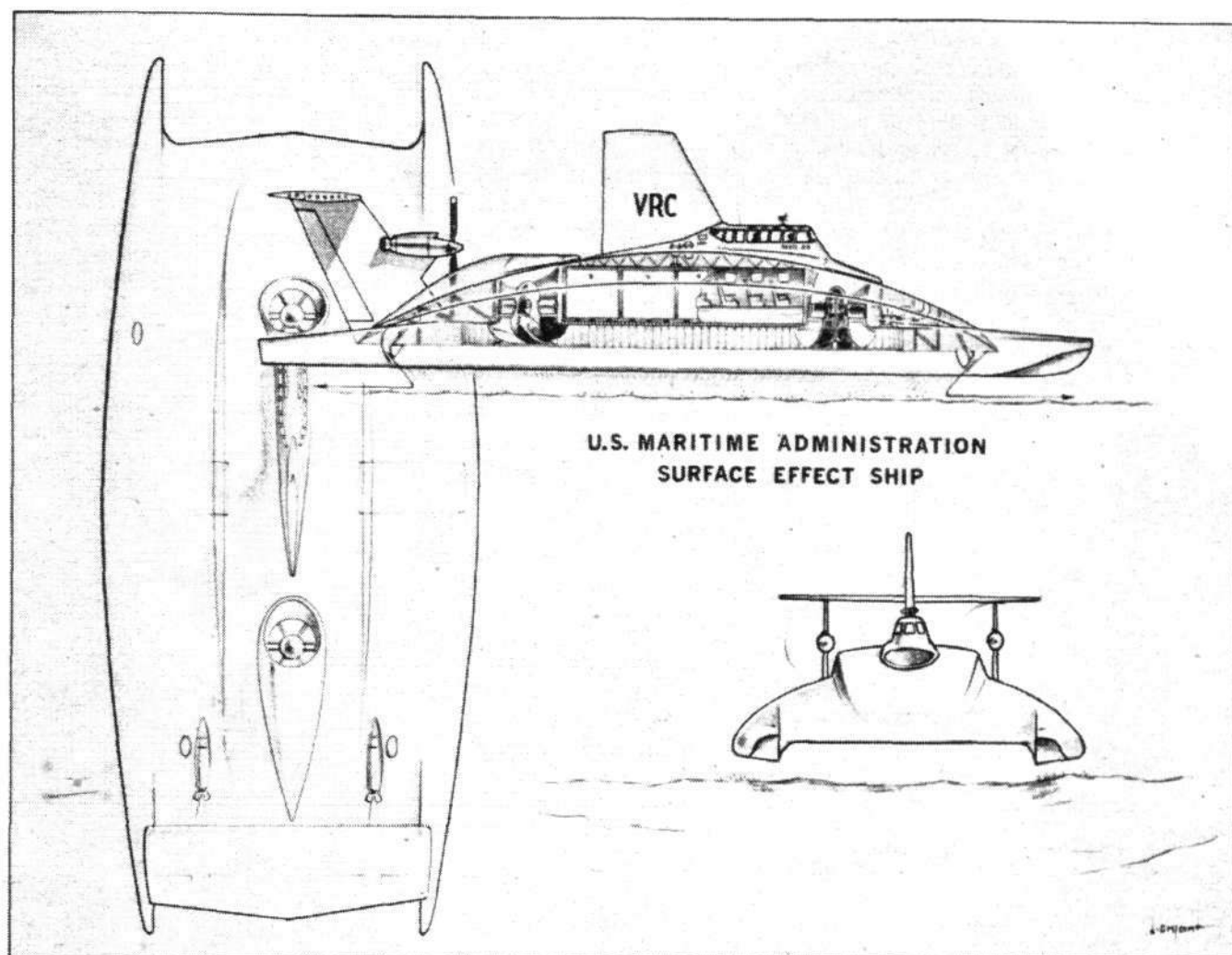


Surface-Effect Ship



Provisional three-view of the 200,000lb MARAD ship

IN OUR JUNE ISSUE we published a plot of vehicle speed against time (in years) to show the contrasting philosophies in the ACV field between Britain and the United States as seen by the US Maritime Administration. Whereas the former country has "embarked early on a programme of hardware development, producing a craft of lower performance at an earlier date," the MARAD philosophy is "one of concentrating early effort in a research phase to produce a better-performing craft at a later date."

The quotations are taken from a paper read before a joint SAE/ASNE meeting in Washington by Dr Scott Rethorst, of the Vehicle Research Corp, Pasadena, Calif, and Mr W. T. Potter, of the US Department of Commerce, describing the Surface-Effect Ship—a special form of air-cushion vehicle evolved from a lifting aerofoil with its tips turned down so that, when operating in ground effect, it becomes effectively two-dimensional and lifts without paying any penalty in induced drag.

Vehicle Research Corp is developing a vehicle which at low speeds rides on a

conventional air bubble, generated by peripheral curtain jets, but which has an overall shape having the form of a lifting aerofoil with its tips turned down close to the ground. As vehicle speed rises, so does its own body-generated lift—partly resulting from reduced pressure on top and partly from a "channel" of increased pressure underneath, between the down-turned sides (Fig 1). The spacing of the streamlines shows the constant high pressure underneath, resulting from external compression ahead of the vehicle, and the uniform reduction in pressure around the top and down the sides "eliminating any shed vorticity or induced drag."

This idea appeared promising enough in 1960 for the US Navy (Office of Naval Research) to issue a solicitation for bids in January 1961. The winner was VRC, who had previously conducted extensive research into air-cushion vehicles—GEMs, ground-effect machines, in American parlance—chiefly for overland use. In the spring of that year the Maritime Administration became actively interested in the idea, and a contract with VRC was permitted in August 1961, for a commercial version.

VRC set forth the controlling design parameters, while MARAD settled upon a 100-ton (200,000lb) craft. Preliminary design and development testing proved so successful that steps were taken last August to provide money for further work.

Included in this further work is the construction of dynamically scaled man-carrying models. The first of these is a 24ft two-seater and, although details have not yet been published, much can be deduced from the sketch (Fig 2). The crew sit to starboard of the centreline, and the central portion of the upper surface is substantially raised, to increase the effective thickness/chord ratio in this area. There are two centrifugal lift fans and two propellers, and what appears to be an AiResearch gas turbine is near the front fan. There appear to be two jets along the sides formed by gaps left between three (apparently flexible) hollow ducts. The two propellers are presumably driven by shafting from the main powerplant. Stability and control is provided by a central fin and two rear fins and rudders, joined by a horizontal tail.

Construction of this research vehicle

is practically completed, and it should begin to operate this summer. Its design is based upon extensive tunnel testing, in the course of which a lift/drag ratio of 24 has been recorded. This compares with 18 for a modern jet airliner and from two to eight for conventional ACVs, say the authors of the paper mentioned. Moreover, they assert that this value of 24 "should be capable of improvement."

If determinations of stability, control and Reynolds number with the manned test craft prove satisfactory, the next stage will be the construction of an unfurnished, instrumented example of the

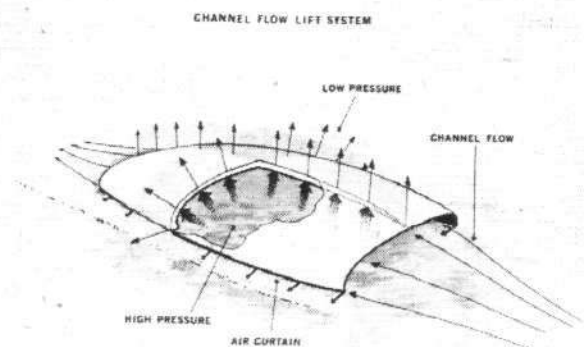
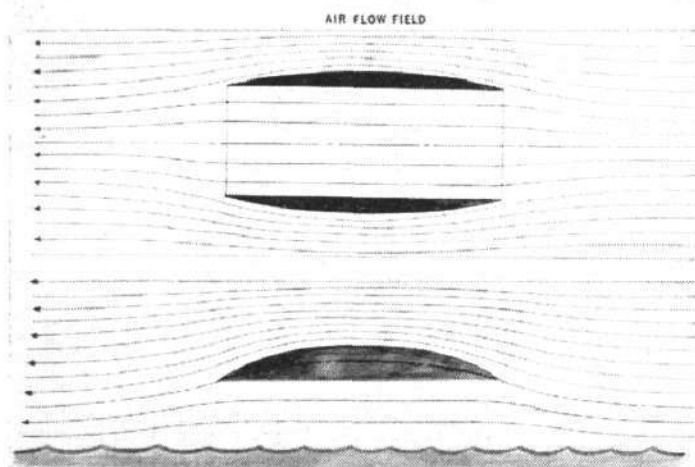
from each of the two pairs of lift engines are coupled to a mixed-flow fan on the centreline, both fans discharging into a common plenum space. This is said to enable the craft to run with either fan shut down, there being no mechanical connection between front and rear fans. Deflection vanes in the side jets provide control for braking and yaw, supplemented by the two propellers (and, apparently, rudders and an elevator). In addition, the big central fin is to provide "a side force for turning" at high speeds.

Structure is expected to cost \$5 to \$10 per lb (presumably in a production

craft), and will be partly of metal and partly glass-fibre. High-strength aluminium alloy in standard forms will be used for primary structure, with corrosion-resistant aluminium alloy for certain areas. Glass-fibre will be used in secondary areas, especially those with compound curvature.

This big and ambitious vehicle is regarded as being of "the minimum economical size"; and the considerable calculated reserve of power is expected to lead to future growth in terms of payload. We shall watch the progress of the MARAD/VRC programme with interest.

Fig 1 The basic concept of the surface-effect ship rests upon the airflow over an aerodynamic lifting body operating in ground effect. In the left-hand illustration the streamlines indicate a reduced pressure above the body (and around the convex sides) and uniform increased pressure over the entire undersurface. In the right-hand sketch the channel-flow lift system is depicted applied to a vehicle with side air curtains



definitive 200,000lb ship. The latter is envisaged as a commercial (or military) transport vehicle for overwater operation. Most of its characteristics are tabulated in the data, but some narrative amplification of the design is of value.

The most noteworthy feature of the full-scale craft will be a system of flexible side jet nozzles capable of automatically adjusting their height so that they should just clear the water surface. How this may be achieved at speeds greater than 100kt is not explained—indeed Rethorst and Potter admit that the system "still requires considerable further development"—but it is to function without any external power, merely by virtue of "the reaction pressure caused by proximity of the jet nozzles to the surface."

At the same time the main belly of the ship is to ride as high as possible, for lift is "only slightly dependent on the height of the body above the surface." The flexible nozzles will meanwhile keep adjusting their height so that they just clear the water, and are to be stressed to pass through the top of the occasional wave.

Lift power is twice the propulsion power, and the free-turbine outputs

MARAD/VRC Surface-Effect Ship

Type Research prototype capable of eventual conversion to transport use, with design payload of 150 passengers or 80,000lb cargo over a range of about 500 miles.

Dimensions Very approximate overall length and width, 180ft and 80ft, respectively.

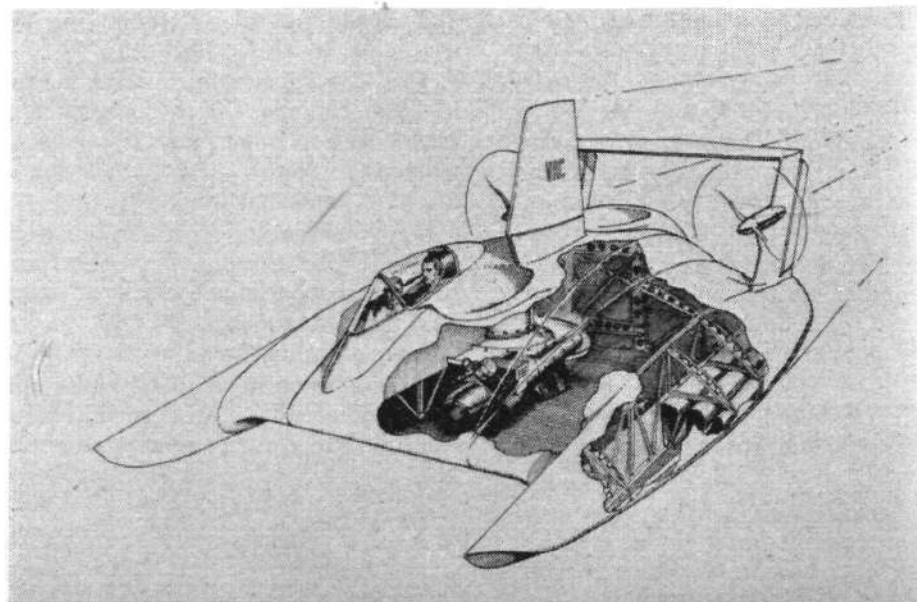
Weights Gross weight, 200,000lb; max payload, 80,000lb (four 8ft x 8ft x 20ft containers); max fuel, 20,000lb; by inference, basic equipped weight, about 100,000lb.

Lift system Fore and aft mixed-flow fans, not coupled together, each driven by two GE T64 turbines each rated continuously at 2,270 s.h.p.; total lift power, 9,080 s.h.p.

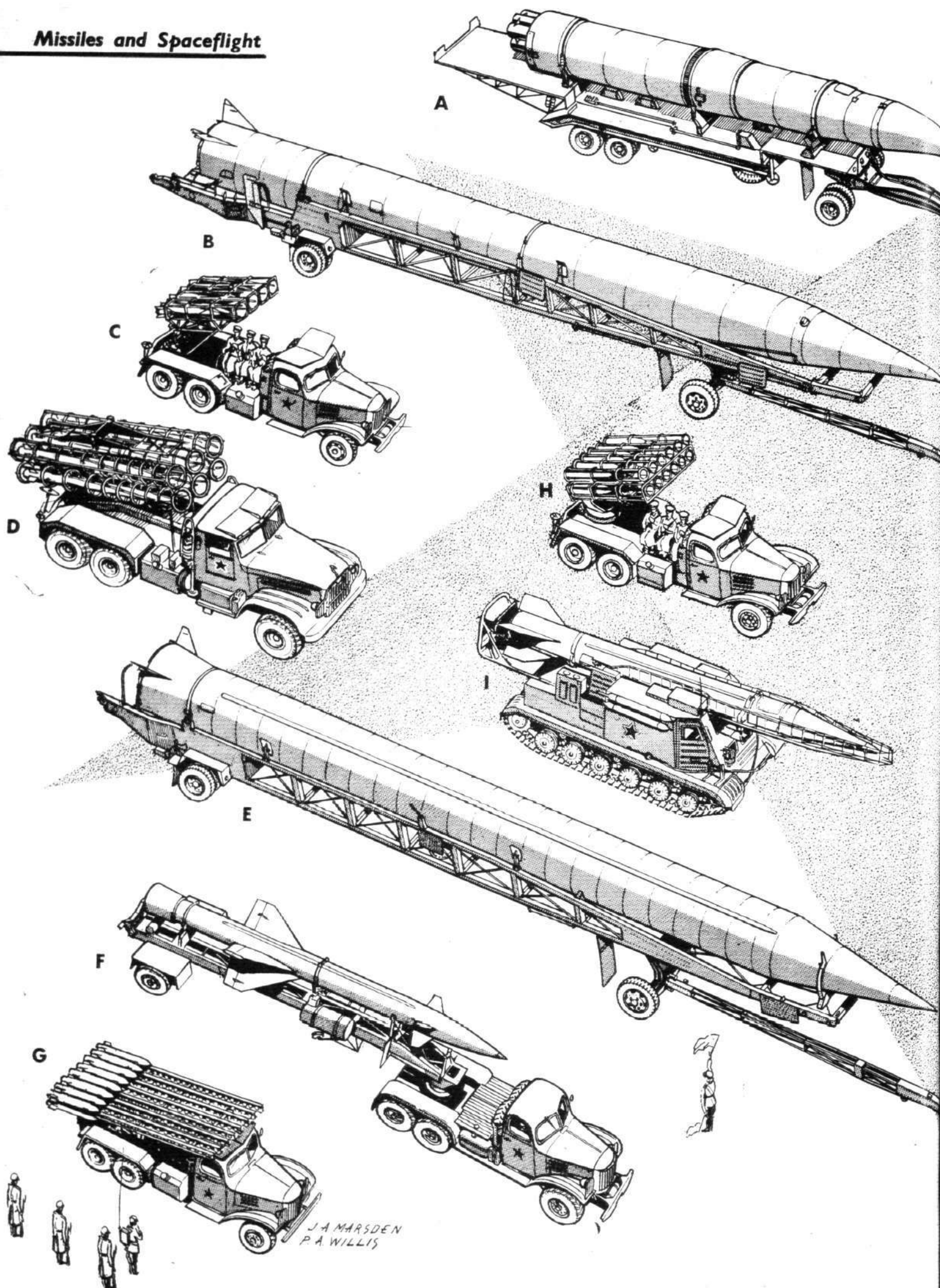
Propulsion system Two variable-pitch propellers, each driven by a 2,270 s.h.p. T64, supplemented by variable rearwards deflection of the side jets.

Performance (estimated) Max speed, 150kt; operating speed for best performance, 100 to 120kt; nominal operating height over rough water, 4ft to the jet nozzles and 9ft clear under the belly, using 9,350 total s.h.p. to cruise at 102kt; operating height over calm water, 1ft (6ft under the belly), requiring only 3,700 total s.h.p.; with development, the suspension system will have a full vertical extension of 6ft, so that the body will ride 12ft above the water with a nozzle clearance of only 1ft.

Fig 2 Most previous ACVs (or GEMs) have been supported almost entirely by their air cushions, and this has limited their speed to about 80kt. In contrast, a low-aspect-ratio wing in ground effect has no immediate limit to speed, but poses stability and control problems. VRC believe they have solved these problems, and are about to demonstrate this with a manned vehicle, shown in cutaway form below. Its superficial similarity to the developed Cushioncraft CC-2, to be used by the RAE in aerodynamic-lift experiments, is noteworthy



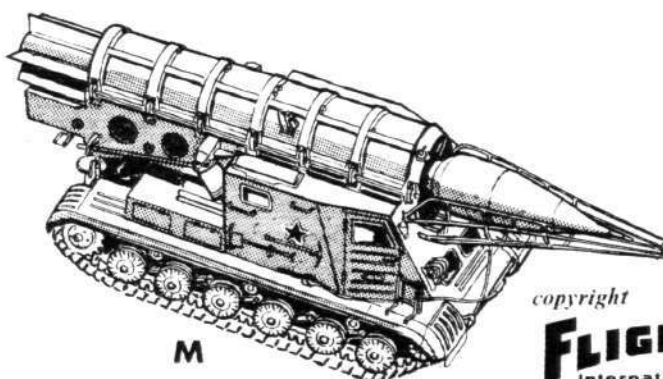
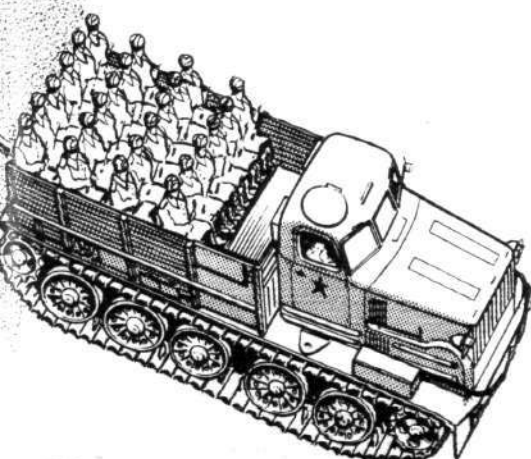
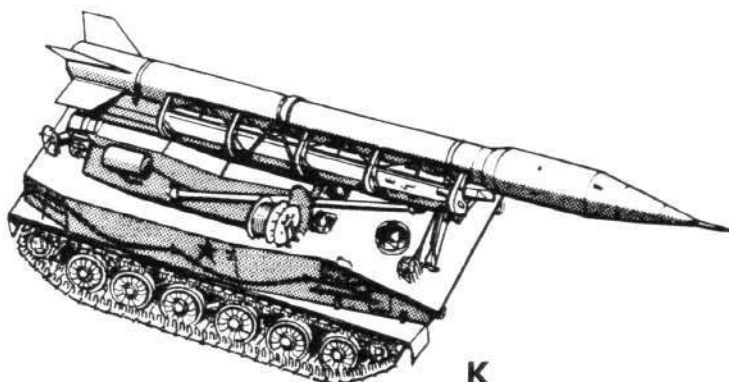
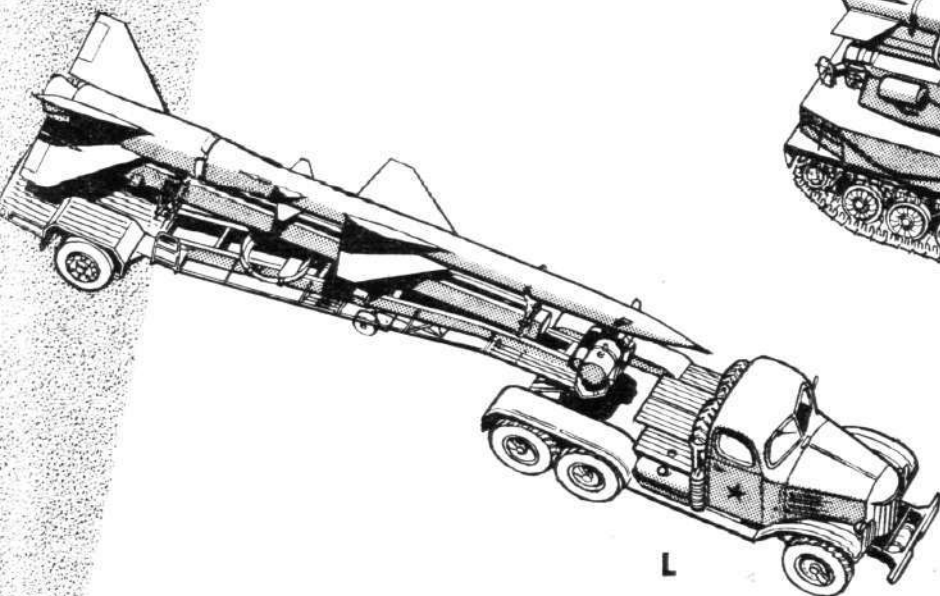
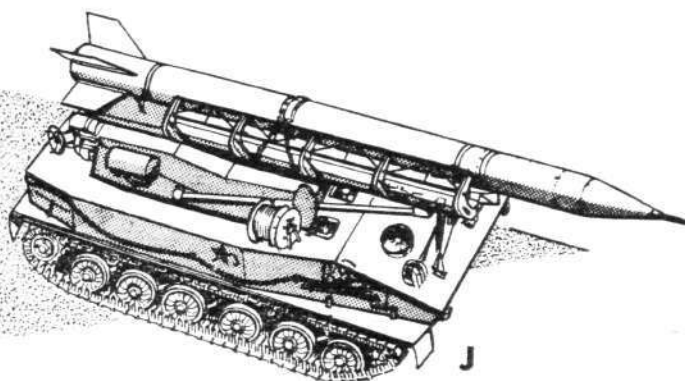
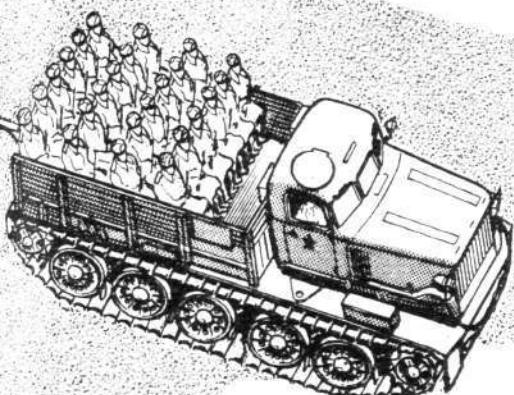
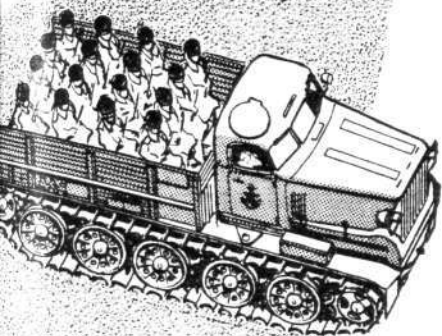
Missiles and Spaceflight



RED SQUARE PARADE...

As described on pages 98 and 99, these sketches depict all the more important military rockets which have taken part in Soviet parades through Red Square, Moscow, since 1957. The illustrations are drawn to a common perspective scale; that is to say, items are drawn as they would appear if the reader were actually present, the scale diminishing slightly from foreground to background

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PRESENT AND FUTURE

DISCUSSED BY W. J. EGGINGTON

A LECTURE DELIVERED on January 15 to the Glasgow Branch of the Royal Aeronautical Society by Mr W. J. Eggington, assistant chief designer, Hovercraft Division, Vickers - Armstrongs (Engineers) Ltd was notable not only for its scope but for the news it imparted of developments at South Marston. The Land-Rover conversion was discussed in considerable detail.

Of the VA-3 Mr Eggington said that although its main purpose was to provide information on the operating capabilities of larger craft, it was being developed into a commercial vehicle in its own right. He went on: "It is interesting to note the considerable differences in the design of the SR.N2 and the VA-3. The SR.N2 has a cushion pressure of nearly 60lb/sq ft and it has a pointed bow and stern, whereas the VA-3 has a cushion pressure of about half that of the SR.N2 and is basically of rectangular shape with a much less pointed bow. This is a reflection of the early state of art. One would suppose that with development there will be some uniformity in configuration for a given application, but of course the configuration will vary with the application. Like the SR.N2 the VA-3 has had engine troubles which limited its performance considerably, and it sustained some superficial structural damage at Rhyl. It is now being repaired at South Marston and before carrying out more advanced operational trials is to be modified to give it a much improved performance. Design is now proceeding on a VA-3 development, which carries 75 passengers and has improved wave riding capability."

A picture was shown of the projected VA-4, differing very considerably from that printed in our October issue. Of

this craft Mr Eggington said: "We shall now consider what future hovercraft may look like. This is an artist's impression of a hovercraft projected at Vickers-Armstrongs and designated VA-4. It is a high-speed over-water craft with an amphibious capability and is a logical follow-on from the basic concept of hovercraft and the early development craft. Typical data for a craft of this type are: All-up weight, 100 tons; total installed power, 13,000 h.p.; payload, accommodation for 240 passengers plus 24 cars; overall dimensions, 140ft by 50ft; speed, 75kt in waves up to 3ft. Scheduled service would continue in seas of wave height 6-7ft.

"Such a craft would have an operating cost of the same order as competitive vehicles. It employs flexible members and would operate in coastal or sheltered waters. It could, for example, operate over the English Channel in spring and early summer, but in winter months it would be found that there would be too many days on which operation would not be practical. Nevertheless, there would be a number of places in the world where it could offer a car and passenger ferry service with a substantial time saving on existing vehicles and at competitive fares."

In considering how hovercraft could be made more efficient Mr Eggington mentioned recirculation, but considered that a more promising approach was reduction of the area of the air curtain. "The most simple means of doing this," he said, "is partly to seal the cushion with solid members. Of course, the members must be introduced so that they do not incur large loads upon the craft. One example of this mechanical sealing is to introduce sidewalls which project downwards at the sides of the

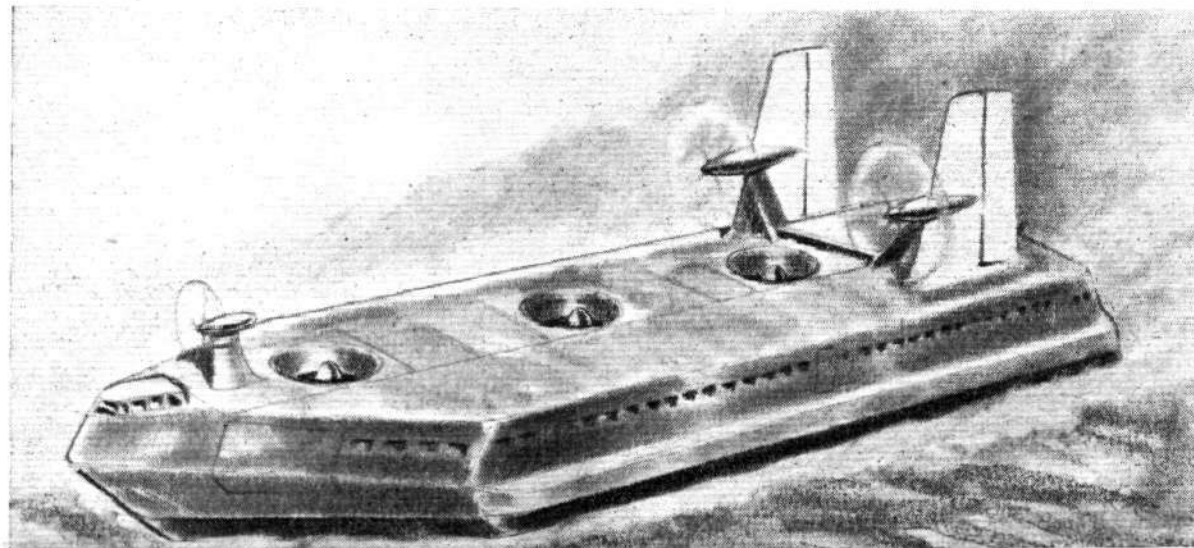
craft below the surface level. On such a craft power is required merely to maintain the air curtain at the front and rear of the vehicle, but the price one pays is the loss of the amphibious capability and also the speed is restricted to some 45kt. Above this speed the hydrodynamic drag associated with dragging the side walls through the water exceeds the power saving due to the reduced curtain area.

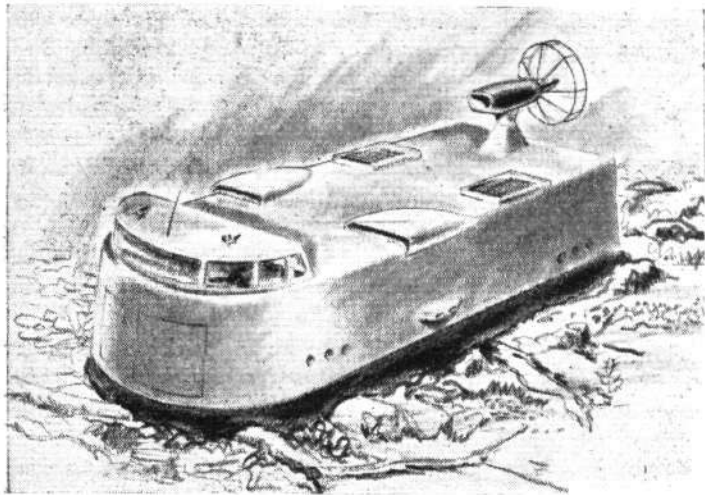
"For general applications over all surfaces the curtain area is best reduced by the use of flexible members. These have the advantage that the resistance to water and impact loads associated with the flexible members striking the surface are limited. This slide [reproduced—Ed] summarizes the different ways in which flexibility may be used.

"The general problem is to introduce members manufactured of flexible materials or members flexibly mounted on the craft's main body which readily respond to waves or rough country. The moving parts may be persuaded to respond by one of three means.

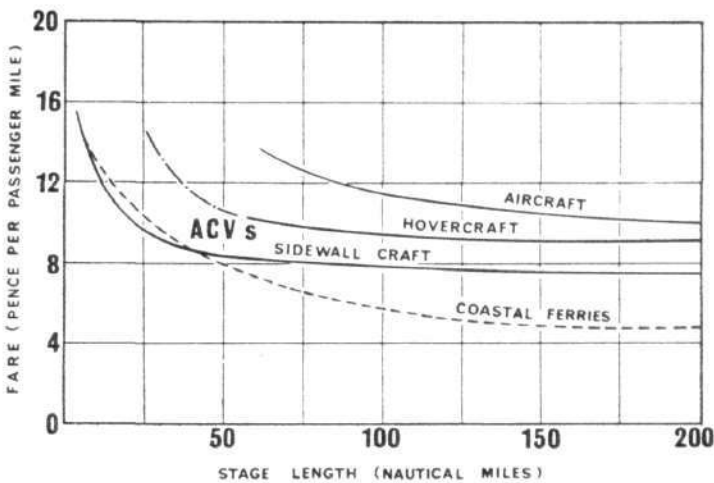
"The first group of flexible hovercraft have flexible members which are actuated by contacting the surface over which they operate. This type has been used on a number of craft, although there is still room for development. It is not essential for flexible hovercraft to contact the surface, however; for example, the moving parts of the craft may be actuated by cushion pressure as illustrated in the second picture. This type of craft consists of a number of cushions or cells around the periphery of the craft and each flexibly mounted. The main craft weight is taken by the central cushion and the outer cells merely actuate the flexible parts.

Latest configuration of VA-4





Flexible hovercraft, primarily for overland use



Fares against stage lengths

"The craft shown in the top two figures [below] have a somewhat restricted operation. At the higher speeds motion of the flexible parts will tend to lag behind the waves, resulting in an increased air gap between the craft and the surface. For the flexible parts to follow closely the surface at higher speeds it is necessary for them to have high accelerations and to receive warning of approaching waves. To do this the flexible parts must be powered, as illustrated in the lower figure. For such a craft a sensing device and servo system are employed.

"It should be pointed out that the flexible material used in the top figure may be used in conjunction with either the pressure-actuated or power-actuated systems. Such arrangements would incorporate both flexible materials and flexible mountings, i.e., two stages of flexibility. These composite systems offer higher accelerations at the bottom of the craft and promise good wave-following capability."

Later in his lecture Mr Eggington showed a graph [reproduced] plotting fares for a range of stage lengths and comparing four types of vehicles. "It must be pointed out," said the lecturer, "that, whereas the fares of the aircraft and coastal ferries are those

currently paid by passengers, the fares for the two air-cushion vehicles are estimated. There is a reasonable basis for the estimates, however. The cost of operating the craft is an extrapolation of the first-hand experience obtained on smaller craft and the main inaccuracy is terminal cost, which fortunately represents a small proportion of the total cost.

"The graph shows that one might expect the fares for air-cushion vehicles to be between those of coastal ferries and aircraft. On a fares basis the attraction of each of the four vehicles is completely in reverse order to that when considering journey time. From the graph one would expect the higher-speed hovercraft to be used mainly for passengers and cars. With the reasonable fares of the sidewall craft, this might be used for transporting some types of freight.

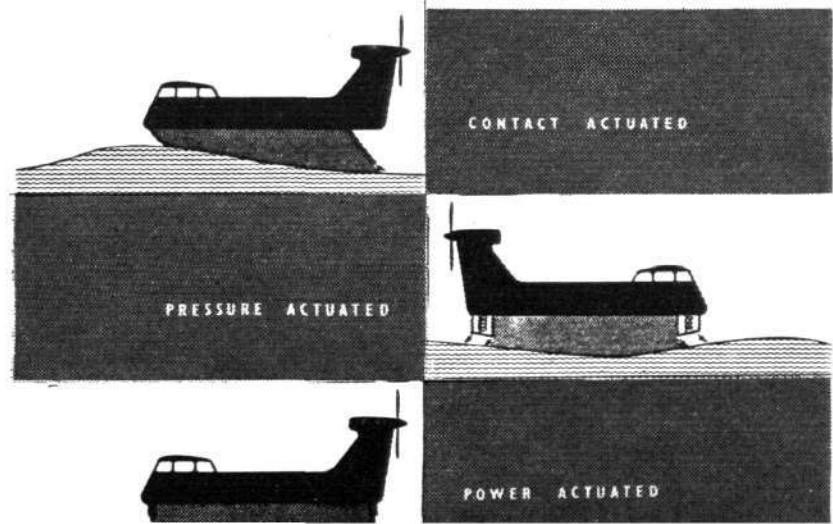
"A consideration which is of the utmost importance to the introduction of the hovercraft into service is the possibility of operating directly over routes while other vehicles have to take a much farther journey. To take the classic example near home, the hovercraft can take a straight line route from Liverpool to the North Welsh coast, whereas both land and conven-

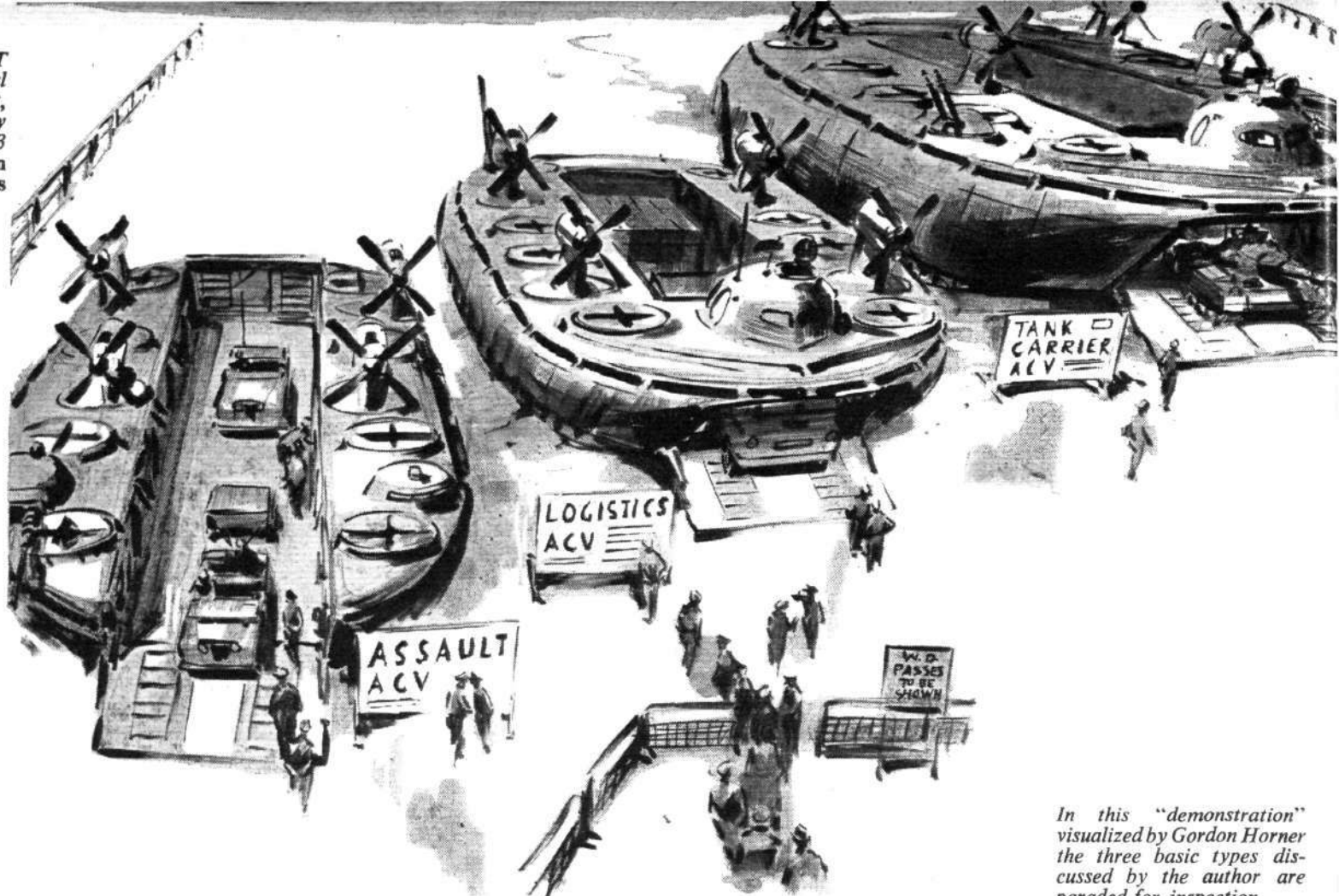
tional marine craft have to travel further distances. The ability of air-cushion vehicles to operate over deep water, shallow water, mud and sand is of considerable significance for short-range coastal ferries."

Although the hovercraft was originally intended for over-water operation, said Mr Eggington, its air cushion enables it to negotiate any surface with limited slope and height of obstacles. He illustrated a typical configuration—reproduced herewith—of a craft intended primarily for operation over land. "Its main attraction," he said, "is that it can operate over marsh, casual water and surfaces having a degree of roughness. This craft employs a flexible skirt of sufficient length to ensure that the rigid main body passes over the maximum obstacle height for which the craft is designed. This particular craft has air propulsion, but for overland operation there is a good case for a craft taking a high proportion of its weight on an air cushion, with wheels that partly support the craft. The wheels can then be used for traction in addition to providing stability and control. Over-land craft of this type could operate over some parts of the world where there are virtually no competitive vehicles, in Canada for example. One would expect that the introduction of over-land hovercraft in these parts would not depend to the same degree upon direct operating cost, but capital cost, reliability and ease of maintenance can be expected to be of the highest importance.

"Apart from the air-cushion vehicle designed for over-land operation, there is a good case for taking an existing land vehicle and modifying it so that some of its weight can be taken on an air cushion for operating off the road." Mr Eggington showed a photograph of a Land-Rover which was modified in this way by Vickers-Armstrongs. "The air cushion," he explained, "is contained

Ways in which flexibility may be used





In this "demonstration" visualized by Gordon Horner the three basic types discussed by the author are paraded for inspection

ACVs FOR THE ARMY

by Major A. J. D. Hughes, RE
SKETCHES BY GORDON HORNER

PART THREE: POSSIBLE SPECIFICATIONS

PARTS ONE AND TWO of this article have outlined the surface limitations of ACVs and the possible roles of such vehicles in Army service in comparison with land-vehicle equivalents. It has not been the primary aim to list or discuss the many other military uses to which ACVs could be put, but some of these ought to be mentioned briefly.

Possible Additional Roles

Ferries A major problem is that of transporting main-battle tanks and a mass of wheeled vehicles across rivers. "Sapper" units at present use, in addition to bridges, a Heavy Ferry with hydro-jet propulsion. Such conventional water-displacement craft, even with low draught, a grounding capability and large ramps, are often limited to river crossing-places with good land approaches, ample ferry construction areas and suitably deep water. Developments of Gillois-type bridges, based upon self-propelled pon-

toons (both overland and in the water), assist in the rapid construction of pontoon bridges and rafts, but these are similarly limited.

Here, then, is a possible role for ACVs. Either air-cushion assistance could be given to the self-propelled pontoons to improve their cross-country performance and to reduce their draught in the water, or a true ACV ferry system could be adopted.

The advantages of a true ACV are that loading and unloading can be done overland and that river currents and depths are no obstacles. SR.N2 already answers some of these latter requirements and can carry men and Land-Rover-type vehicles. In the context of this article the logistic-supply ACV and tank-carrier ACV could also do this. Engineer effort would generally be required to prepare suitable ramp approaches on the river banks.

As with the possible solutions using the air-cushion-assistance principle dis-

cussed under "Armoured Fighting Vehicles" in Part 2, such measures may mean getting the worst of both worlds. Overland, extra planform apparatus is required. In the water this may also be true and may result in a generally less manoeuvrable craft, which, although of lesser draught, will have a higher centre of gravity and may require more propulsion power. Where pontoons can be joined together to form a base suitable for an ACV a gain may be achieved in that the draught is much less than normal, but the power requirement will involve much extra weight and increased complexity. The true ACV advantages of high speed and an effortless amphibious capability are not likely to be achieved.

It may also be relevant to recall that a conventional displacement ferry is an inefficient method of transporting vehicles across a river. Its capacity can never compare with that of a bridge, and future combat formations can expect

MILITARY APPLICATIONS OF HOVERCRAFT

BY CAPT GUNNAR GRANDIN, Royal Swedish Navy



As recorded in our December issue, a paper entitled as above was delivered at a recent symposium in Stockholm. The author was Capt Gunnar Grandin, to whom we are indebted for the text and illustrations reproduced herewith. Capt Grandin graduated from the Naval College in 1940 and took the Staff Course and Technical Course at the Naval Staff College between 1946 and 1948. Since 1960 he has been chief of the Planning Section at the Naval Staff, Stockholm. This section is responsible for long-range planning and operational research.

THE SUBJECT OF MY LECTURE is "Military Applications of Hovercraft." To start out with I must confess that I know absolutely nothing about it. There is no military Hovercraft yet. Now, having settled the level of what I am going to say, I intend to go ahead and give some points of view on military purposes for which Hovercraft might be used.

Definition of Combat Value

The combat value of a weapon system can be said to be composed mainly of two factors, i.e., striking power and power of resistance. By "effectivity" we mean the possibilities of getting the system into action as well as its capacity for developing fire-power. By "power of resistance" we mean on one hand the power of avoiding hits, on the other the degree of protection against hits. Consequently, mobility can affect effectivity as well as power of resistance. A mobility contributing to increase effectivity, to

bring weapons to bear, we call offensive mobility. A mobility rendering it difficult for the enemy to use his own weapons we call defensive mobility. Basing my arguments upon this division of combat value, I will try to examine the military possibilities of Hovercraft.

Offensive Mobility

I begin with offensive mobility, i.e., the power to get a unit or weapons to work.

The techniques of transport, where the combination of mobility and transporting capacity decide the matter, has been a factor which has attracted military interest for thousands of years. The question is whether it is not really the transport problem which is the principal problem of strategy as well as of tactics. I will mention some examples of revolutionary solutions of this problem from a military point of view.

An invention, the importance of which it is perhaps a little difficult to understand today, was the two-wheeled war chariot drawn by horses. When it replaced the slow, four-wheeled ox-wagon, about the year 1500 BC, the armies of the Near East obtained quite another kind of mobility, strategically as well as tactically. That was one great military transport invention.

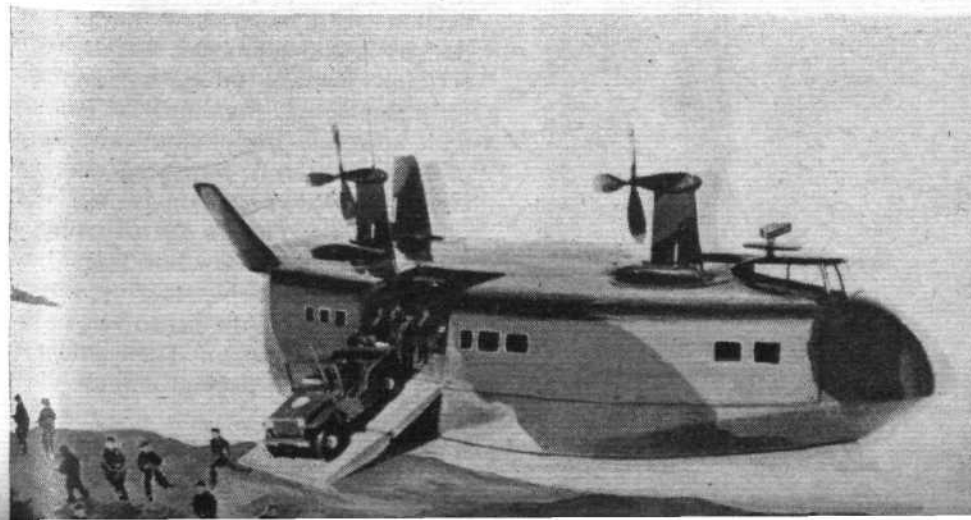
A later, but perhaps more obvious, parallel to the subject of the symposium today, were the ships of the Vikings. As you know, people have always wondered how the Vikings could operate

with such great success for such a long time with their pirate expeditions. How was it possible that, being only very few, they could bring about so much damage in the populous countries on the Continent? The secret may lie in their ships. Their design was quite exceptional. They were very light, of strong and, at the same time, flexible construction; they were fast and at the same time shallow-draft ships; they could be sailed or rowed close to a shallow shore. Those who have made a more thorough study of the expeditions of the Vikings have found that generally their raids upon the coasts were made on places far from fortified places. The navigating conditions were such that ships with ordinary draught could not arrive there. Furthermore, the raids were carried out so quickly that there was no time for defenders from fortified places to intervene. The ships could withdraw by sailing, or, when there was no wind, they could be rowed. As a matter of fact, there was no defence against them. The advantages that these ships showed over their contemporaries are perhaps what, from a military point of view, we demand from the maritime means of transport of today, though on another scale.

One application of the offensive mobility of Hovercraft is the same as for the Viking ships—to transport troops with or without heavy weapons. Speeds of up to about 100kt, or perhaps more, do not seem impossible. This speed is high compared with that of conventional ships, though not very high compared with aircraft. It is, however, speed in combination with a high load capacity that renders Hovercraft something new. In this regard they may have a place between ships and aircraft.

Their next quality, affecting offensive mobility, is relative independence of the medium over which they are driven—water, ice or whatever it may be. This is perhaps of still more importance than the high speed. A Hovercraft does not require a harbour or a landing-ground in a conventional sense: it may be "parked" within a very limited space. In this way the loading of troops may

Fig 1 The Westland SR.N3 operating as a landing craft



MILITARY APPLICATIONS OF HOVERCRAFT...

take place practically anywhere. In disembarkation operations of conventional type we need harbours or a special disembarkation technique from landing craft on an open shore. The Hovercraft can—if the coast is fairly suitable—go up on the shore and unload directly on it. This will, perhaps, give quite new possibilities for disembarkation operations and may perhaps also change their character.

The independence of harbours for the embarkation of troops may become especially important in the age of atomic weapons. Invasion fleets of conventional ships, gathered in a port, have without any hesitation to be considered as targets worthy of atomic weapons. This will hardly be the case with invasion ships of Hovercraft type, holding a dispersed formation on a shallow coast. It may prove that long shores with shallow water and without harbours, which have formerly been quite impossible from a navigational point of view, will be the best ones for Hovercraft.

How is a Hover-landing craft going to look? Fig 1 is a picture of SR.N3 in a military version. A conventional landing craft uses its stem for unloading; this is obviously not necessary for a Hover-landing craft.

The independence of the medium over which the Hovercraft will pass may be of special importance in the waters of Northern Europe. In many of the coastal waters there is ice, making it difficult, especially for small ships, to enter or leave the ports. At sea, the Gulf of Bothnia and the Bothnian Sea are covered with ice every winter. The inland waters of the North-European countries are also frozen. Hovercraft may considerably increase the possibilities of using these watercourses for traffic. It must, however, be remembered that it is not always possible to

pass with Hovercraft over waters covered with ice. In many areas of the Bothnian Sea and in the Gulf of Bothnia—especially just off the coast—there is pack ice. Icing-up is another problem to which special attention must be paid (see Fig 2).

The Scandinavian coastal waters are full of rocks; therefore navigation is often difficult. Owing to the fact that Hovercraft have no underwater hull, they can navigate independently of rocks. In that way it is easier to pass without knowing the waters, and furthermore, it is possible to go straight on and consequently to arrive more rapidly at the destination.

Before the radar age it was possible, under cover of night, to achieve surprise, even by means of ordinary, not-too-fast ships. Since the invention of radar and other modern means of reconnaissance the possibilities of an air-landing have offered the greatest advantages from this point of view. The transport capacity of air-landing is, however, very limited; besides, the landing presents special problems. The high speed of Hovercraft, their relative independence of suitable disembarkation shores, and their good transport capacity, may considerably increase the risks of surprise invasion operations. The Hovercraft will—if this expression may be allowed—widen the maritime road for rapid invasion transports.

The military function of Hovercraft about which I have spoken—that is as landing craft—is already a fact. Most of those present have travelled by Hovercraft of one type or another. In favourable circumstances, all existing Hovercraft may be used as landing craft.

Offensive mobility may also be exploited to transport weapons against the enemy, against his invasion craft, against the protection forces, against raiding forces, against submarines, and for mine laying. The necessity of using fast weapon-carriers with a high fire-power is, of course, increased in the same proportion as the mobility of the



Fig 2 "Icing up is another problem to which special attention must be paid"

enemy transport craft and warships is increased. The general advantages of quickly arriving at the place of attack I hardly need to mention.

Fire Power, Weapons

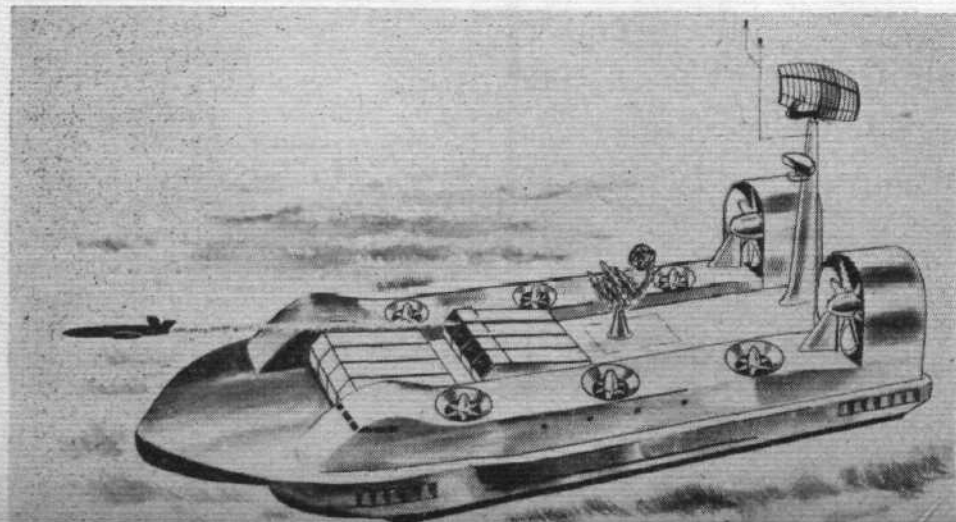
Which are, then, the most suitable weapons for a Hovercraft? These craft are light ships; the types developed up to now are comparatively small. Therefore, the gun is perhaps not a suitable weapon system. Otherwise, a quick-firing gun with a moderate range would be an excellent defence weapon, specially as a defence in the vicinity of the coast and in an archipelago.

I think, however, that guided missiles with built-in driving power, and which do not require a very steady and heavy foundation, go much better together with Hovercraft than guns do. Missiles of comparatively long range, as well as those having a shorter range, may be considered. I mean, in the first place, ship-to-ship missiles. Certainly, that is not to say that it will not also be possible to install ship-to-air missiles. This ought to be an easy way to increase the mobility of anti-aircraft batteries.

Hovercraft—such as they look today—can, of course, be equipped with conventional torpedoes. What is required is a loading capacity of some tons. I am, however, not sure that torpedoes are the best weapons for a Hovercraft. There is no good balance between the fast platform and the relatively slow torpedo. But we have had torpedo aircraft, so there might still be a reason for torpedoes on board a Hovercraft.

Another task spoken about in connection with most new naval craft designs is anti-submarine warfare. It is certainly possible to use a Hovercraft for this purpose. Preliminarily, I cannot find, however, any obvious advantages of the Hovercraft compared with the combined system of a conventional ship plus helicopter. This is, of course, a matter that should be studied, and then the problem will be whether the Hovercraft shall replace the helicopter, or the ship, or both of them. The solution of the problem will depend entirely upon

Fig 3 Guided missile hovercraft with long-range surface-to-surface missiles and small surface-to-air missiles for protection



the development of the Hovercraft as regards seaworthiness, manoeuvrability, and silence. At present there is considerable noise. One advantage of the Hovercraft compared with the conventional ship is that it is more difficult to hit by torpedoes from a submarine.

As regards mine-laying, this can easily be done from a Hovercraft. To what extent it can be used for this purpose could be decided through transport-economic studies. In this connection, we also may ask to what extent a Hovercraft is mine-proof. Most of those present know well that there are mines influenced by magnetic, acoustic or pressure effects from passing ships. A Hovercraft emits acoustic as well as pressure impulses into the water and—depending on the design—magnetic impulses also. Consequently it is not mine-proof. It might, however, cause the designers of mines many difficulties, i.e., by its high speed.

Power of Resistance

To give a Hovercraft protection in the form of armour, etc, in order to increase its power of resistance seems to be the wrong way. Its power of resistance will probably be that which is caused by its defensive mobility. This mobility can be used for quick regroupings in wide base-areas. Furthermore, Hovercraft can use camouflaged places ashore as well as at sea. It seems that Hovercraft might have good possibilities in avoiding location and attack by aircraft at their base.

Up to now, I have spoken about the Hovercraft for naval purposes. Undoubtedly its best use is above the surface of the water, for the comparative level and smooth surface of the sea, with ample manoeuvring space, is very suitable. However, it will also be used for military operations ashore. We have already seen several examples of designs intended for use in marshland. Another interesting application, lying between activities at sea and ashore, is transport on inland waterways. Lakes and rivers which are not navigable with conventional ships may be of importance in this connection.

Summary

I have now spoken about the Hovercraft as though it is an invention which will solve practically all the problems of the naval warfare. This will probably not be the case. I have made a survey of the possible military applications of interest if a developed product fulfils what the preliminary technical prognoses promise. Further development has two aspects, one technical and one economical. As regards the technical aspect, there are four points which I should like to underline.

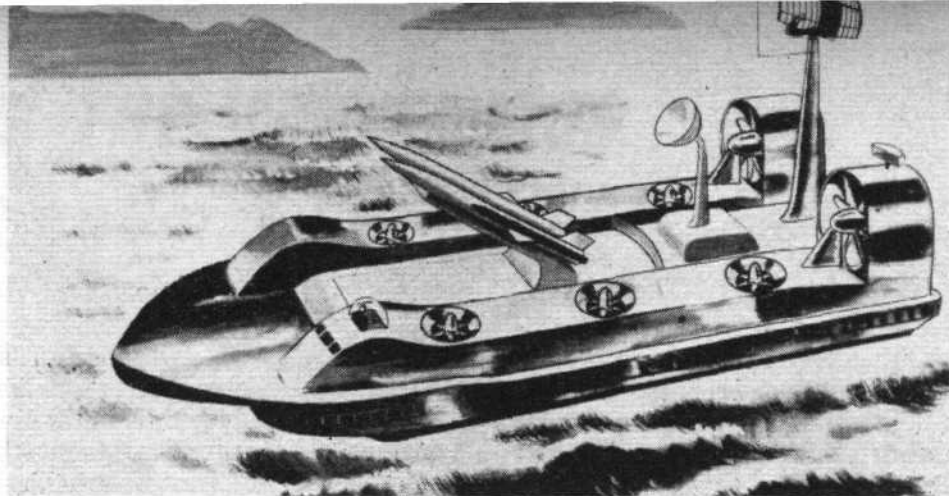


Fig 4 Hovercraft with ship-to-air missiles

The first one is seaworthiness. The Hovercraft must be designed at least to stand a moderate sea. If it does not, it is not worth thinking about for naval use. On the other hand, the demands must not be too heavy. Conventional, small, light craft, such as torpedo boats and gunboats, cannot operate in all kinds of weather: at least, they cannot use their weapons. The flexible skirts seem, however, to be in a fair way of solving the problem.

The design must further be robust—"sailor-proof." Such expensive ships must be durable, too. To operate close to the surface of the water at high speed certainly requires quite a lot of the design. The propelling system must be reliable. It must be possible to count upon lives of 10-15 years.

Speed has to be maintained, even in moderate seas. However, this is connected with the first point—seaworthiness.

Finally, manoeuvrability should be improved. This demand is, however, not as severe as the two first ones. It is possible to adapt oneself quite a lot to the degree of manoeuvrability.

As regards economy, it is most important to reduce the cost as much as possible. As you know, practically all weapon systems show the same development: in an early phase of prognosis performance is high and cost is low; but

gradually the curves of the two qualities are getting nearer to each other.

Comparison between Cost of Hovercraft and Displacement Hulls

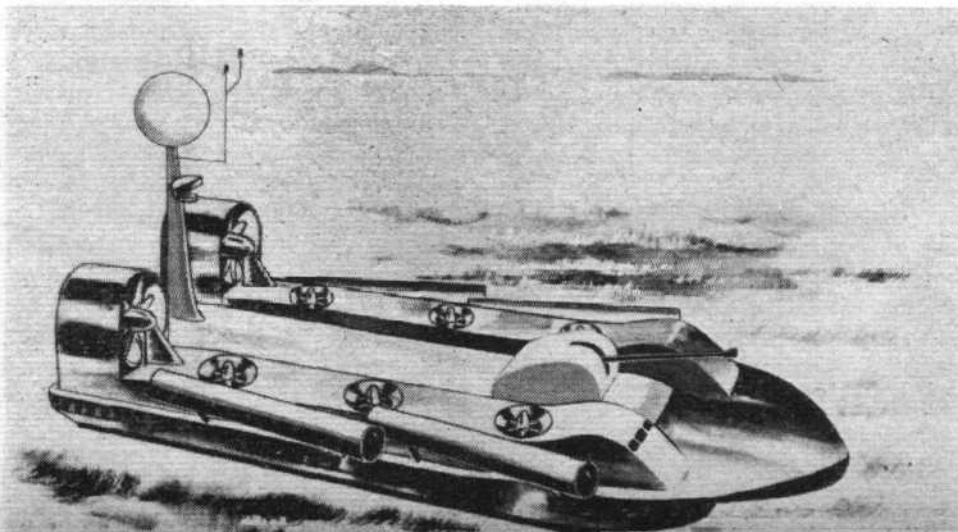
Weapon weight (tons)	Type of vessel	Speed (kt)	Cost (\$w mkr)
12	Hovercraft	80	16
	"Brave" hull	60	11
21	Hovercraft	80	27
	Torpedo boat	50	15
	Motor gunboat	24	7
44	Hovercraft	80	45
	Conventional	24	11

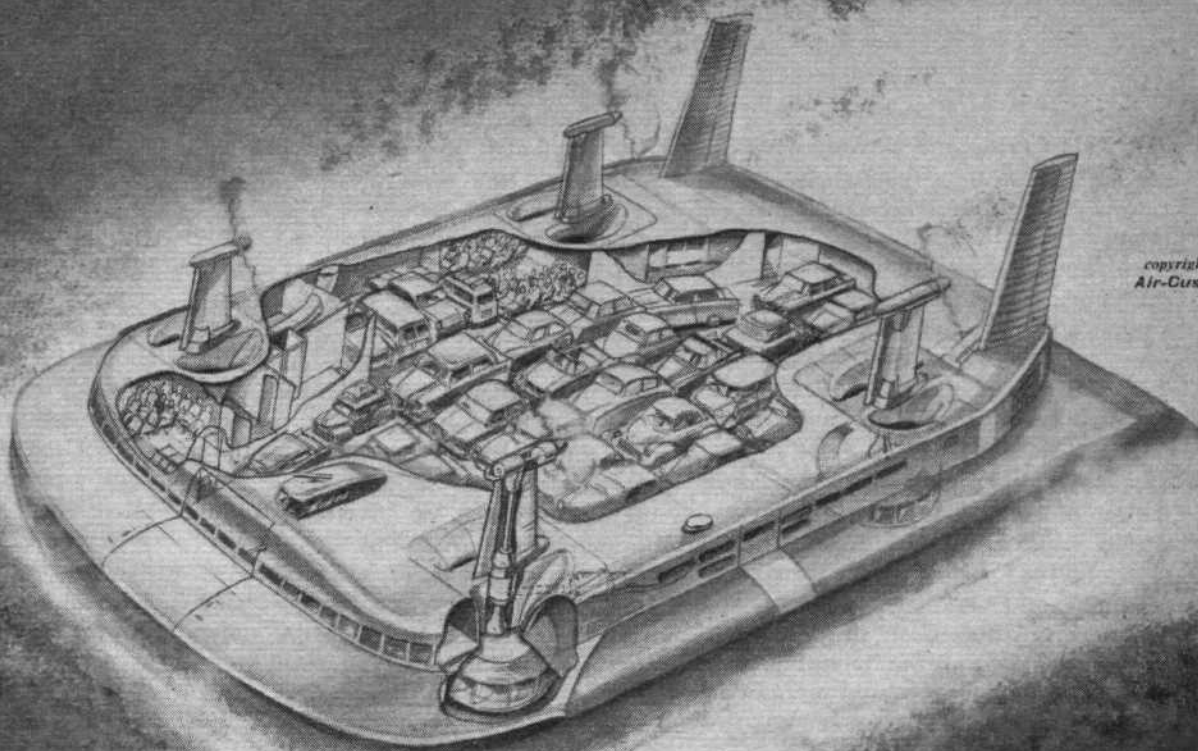
Hovercraft costings are as yet precarious, and vary, *inter alia*, with demands on accommodation.

It is obvious that in present conditions the choice between Hovercraft and conventional ship is rather difficult. The former has high speed; however, also a higher price. The curves of cost and performance remain as expected. There is no "saddle point."

Finally I feel that some answer should be given as to whether Hovercraft have a military future. That answer should not be given by military people. As I pointed out, warfare is to a large extent a transport problem—to get troops and weapons to the right place in the right time. If there is a platform that can solve that problem better than other platforms, it has an assured future as a military vehicle. As we have heard today, the Hovercraft has many features which, properly developed, can outmatch existing vehicles.

Fig 5 Hovercraft torpedo boat





copyright
Air-Cushion Veh

The SR.N4 is depicted here carrying 40 cars and 116 passengers

Hovercraft Channel Link

A REMARKABLE DOCUMENT, titled as above, was made available by Westland Aircraft Ltd late in February. The first part of the text is here given much as received, though a number of the figures—and the second part—are not reproduced. Much new information is imparted concerning the SR.N4, bases for such craft and operating costs and techniques.

Summary and Conclusions

- (1) The report is based upon the predicted growth of traffic published in the MoT White Paper *Proposals for a Fixed Channel Link*, Cmnd. 2137, Sept 1963.
- (2) The main assumption made is that the existing forms of cross-Channel transport, covering both ships and aircraft, would continue to carry approximately the same level of traffic as they would be carrying at the end of this decade, and that the traffic growth beyond this level could be catered for by a hovercraft service.
- (3) The service required to do this and

meet the peak August daily traffic of 13,500 cars would require a minimum fleet size of 16 SR.N4-type hovercraft, although the average August daily traffic would require approximately six to eight craft, and in the winter months one SR.N4 would be capable of dealing with the average daily requirements.

- (4) By introducing three SR.N4 craft into service every two years and with the modest assumption that the craft life would be only ten years, the total predicted traffic growth could be accommodated, and the fleet would build up to 16 craft by 1985.

- (5) The production cost of an SR.N4 would be of the order of £1.15m. With an annual utilization of approximately 900hr per year, the total yearly operating cost, including all overheads and indirect costs, would be of the order of £0.4m per year.

- (6) In order to provide a direct comparison with the fixed-link proposals, one of the assumptions made is that the entire traffic growth to be

carried by hovercraft would go across the classic Dover-Calais route, and on the basis of this assumption it has been found that the total operating cost in 1985 would be of the order of £10m per annum, while the total revenue would be of the order of £18m per annum, if the existing British Railways fares are used for passengers and cars, and if the fairly low Channel Tunnel rates are used for freight.

- (7) Estimates have also been made of a more practical hovercraft service in which routes are distributed. The assumption that appears to be most practical is one where the same total traffic is carried by hovercraft, but only 60 per cent of this is carried between Dover-Calais, approximately 20 per cent between Newhaven-Dieppe, and approximately 10 per cent each between Southampton-Cherbourg, and Harwich-Calais. The great advantage of this proposal is that, by distributing the hovercraft routes, we avoid the considerable congestion of traffic in the Dover

HOVERCRAFT CHANNEL LINK . . .

and Calais areas and provide a useful service across the Channel for West Country and Midland traffic which might more naturally go through Southampton and for Northern and Eastern traffic which might more conveniently go through Harwich. However, to meet this distributed route proposal the number of craft required to carry the same total traffic increases from 16 SR.N4s to 22 SR.N4s.

(8) The total capital cost of providing a fleet of 16 craft to work the Dover-Calais route would be approximately £34m by 1985. This includes the cost of terminals and maintenance bases. The total cumulative cost in the same period including all the operating costs and indirect charges would amount to £106m, against the total cumulative revenue of £192m.

(9) By comparison, if the more practical hovercraft service distributing the traffic on various routes were adopted, using 22 craft instead of 16, the annual operating costs would increase from £10m to £15m, and the total

revenue would increase from about £18m to just over £21m.

(10) The total capital cost of providing a service to distribute this traffic would be approximately £50m by 1985. The cumulative total operating cost up to the same year would be of the order of £160m while the total cumulative revenue would be approximately £230m.

(11) The main conclusion that can be drawn from this study is that a fairly modest fleet of 150-ton hovercraft could be expected to cope adequately with the predicted traffic growth up to 1985 and beyond. The fleet requirements to meet this traffic growth lie between 16 and 22 craft, depending upon the way in which the hovercraft routes are established. With this fleet a hovercraft service could be provided every 5min under peak August Bank Holiday traffic conditions, every 15min under normal daily summertime conditions, and approximately once every 1½hr during the winter months. The relatively large number of fairly small craft allows a great deal of flexibility in providing a service to cope with unexpected traffic peaks, and also to allow the operators to adjust the number of craft in service to meet day-to-day requirements while maintaining a reasonably high and

economic load factor; but perhaps most important of all, such a service could be introduced in parallel with the existing ship and aircraft services to the Continent.

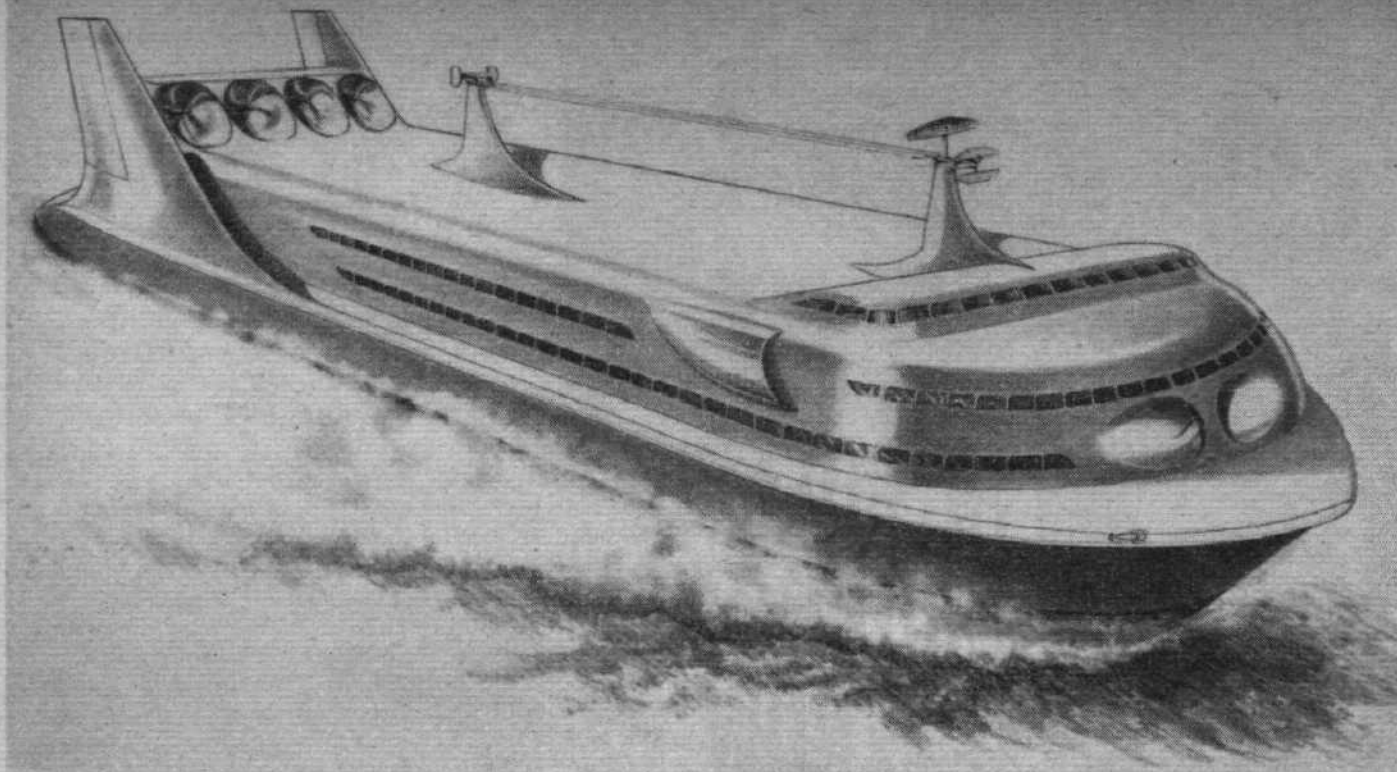
The Potential of Hovercraft in a Transport System**The Hovercraft's Sea-keeping Ability**

In order that a hovercraft can successfully be applied to a particular overwater route, it is essential that it should be capable of operating satisfactorily in the sea states prevailing in the area throughout the year. Thus, one of the major hovercraft performance aspects which requires particular attention is its overwave capability. Westland's experience shows that from dynamic model tests in towing tanks, full-scale overwave performance can be predicted with a high degree of accuracy.

It has been proved on the 27-ton SR.N2, which is only 60ft long, that the ride is comfortable in up to 3ft waves and winds of up to 25kt, and that the craft may be safely operated in waves up to 6½ft and wind speeds of 35kt, although the hover height, or daylight clearance, is a mere nine inches. This overwave performance has been made possible by

An SR.N4 "hoverport," with brisk business in progress





This Bristol Siddeley artist's impression of a future ocean-going ACV borrows the bow-thruster propeller idea now current on large liners and features a large fan in the forward superstructure giving port or starboard sideways thrust for better controllability in harbours and confined waters

GAS TURBINES FOR ACVs—PAST, PRESENT AND FUTURE

THE AUTHOR'S COMPANY has been at the forefront of hovercraft engine development since the inception of this revolutionary vehicle industry in the United Kingdom. Each of the engines supplied to date originated from aero gas turbines. In the early 1950s when Mr Cockerell was busily engaged in developing the air-cushion vehicle principle, Bristol Siddeley were turning their attention to the use of aero gas turbines for marine and industrial applications.

It was realized after the Second World War that propulsion of high-speed conventional craft would be an ideal application for such engines and the first advances were made when the British Admiralty decided to adopt the Proteus engine (Fig 3) to power "Brave" class fast patrol boats designed by Vosper Ltd, of Portsmouth.

The cost of developing high-performance gas turbines specifically for this use is so high that, economically, it is out of the question to do so. The Admiralty took full advantage of the large sums of money already spent on the Proteus during aircraft development and used the engine with the minimum of change.

The main advantage which justifies the use of aero engines in the marine field is their low weight and volume characteristics. Their use is particularly appropriate on high-speed craft where performance can be achieved which would be impossible with any other type of prime mover. Specific engine weights are in the order of 0.7lb/h.p. and specific

volumes are less than 0.1 cu ft/h.p. Large gas turbines above 10,000 h.p. have fuel rates at economical power of around 0.55lb/h.p./hr. Engines below 10,000 h.p. have specific consumptions generally in the regions of 0.6 to 0.8 lb/h.p./hr.

Other advantages over conventional marine engines are: more rapid starting and acceleration; high torque at low rotational speed; large horsepower sizes available; simplicity of construction; ease of and reduction in maintenance; lower installation costs.

The main disadvantage over conventional prime movers is high fuel consumption.

Choice of Marine Rating and Overhaul Life

When considering aero gas turbines for use in the marine field, it is necessary to assess the effects which the changes in environment and load may have on the operation of the engine. Modifications to the unit which affect its power rating are usually necessary to meet the new requirements satisfactorily.

When deciding the performance rating for marine use the following factors require consideration:—

More protracted periods of operation at the full marine rating will be required and the percentage of total operating time above the cruise rating may be in the region of five per cent.

The engine will operate at sea level.

Diesel fuel having a higher sulphur content than normal aircraft turbine

fuel will be used in marine uses.

The engine will be subjected to salt ingestion from sea water which tends to foul the compressor blading and cause corrosion, notably of the turbine blades.

An overhaul life of between 1,000 and 2,000 hours is usually required.

The choice of marine rating is, therefore, a question of running an engine at as high a temperature as is consistent with achieving the required overhaul life. The factors which limit overhaul life can be divided into three broad classifications, namely:—

High turbine-entry temperature causing creep limitations on hot components and possibly limiting flame-tube life.

Mechanical failures due to high pressure loading, for example, thrust bearings and blade fatigue failures.

Corrosion due to salt water and the presence of sulphur in the fuel.

Allowing a temperature margin to cater for increase in intake temperature and the effect of salt deposition on compressor blading, Bristol Siddeley run marine engines with a turbine entry temperature of about 100°C below the equivalent aero engine take-off value. This ensures that the life of the turbine components will not be limited by creep and adequate flame-tube life.

Regarding the possibility of mechanical failures due to pressure loading, bearing in mind that the marine engine will always operate in full sea-level air pressure, we have found it more relevant

INTERNATIONAL NEWS . . .

ground with gradients up to about 15 per cent."

Gross weight will be just under 3,000lb, length about 19½ft, and maximum speed approximately 50kt.

Round the Island

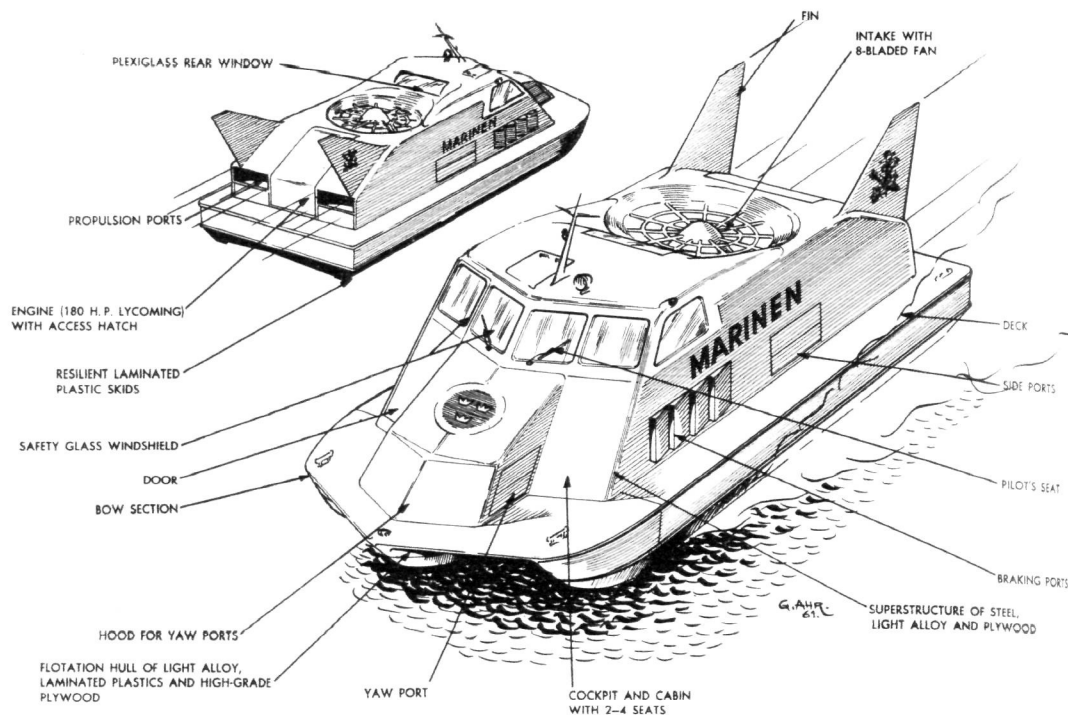
On July 25 the Westland SR.N2 made a circuit of the Isle of Wight in just over one hour. The makers state that the total distance covered was 51 n.m., giving an average speed of more than 50 m.p.h.

In command was Lt Cdr Peter Lamb, chief test pilot of the Saunders-Roe Division of Westland Aircraft, and among the 14 people aboard was the Division's chief designer, Mr R. Stanton Jones, who was responsible both for the SR.N2 and its historic predecessor SR.N1.

The trip was part of an intensive development programme aimed at obtaining certification of SR.N2 for passenger carrying prior to the second regular service, inaugurated between Ryde, Isle of Wight, and Southsea on August 13.

BBC Documentary

Continuing their coverage of air-cushion vehicle development, BBC Television showed, on August 8, a most interesting and entertaining 35min documentary film entitled "Hovercraft." By skilful dramatization and excellent animated diagrams it showed how Christopher Cockerell's earliest experiments to cut down the drag of boats by "lubrication with a film of air" were



Sweden Too: The Saab 401 air-cushion vehicle now nearing completion and is the subject of a news item on the preceding page

developed into the first large-scale trial vehicle—SR.N1.

After a number of historic SR.N1 sequences, the film went on to show the expanding air-cushion vehicle industry in this country, with laboratory testing and workshop scenes taken at Vickers-Armstrongs and William Denny. Following a series of remarkable shots of the Britten-Norman Cushioncraft, Vickers-Armstrongs VA-3, the Denny D.2 and Westland SR.N2, the film concluded with a delightful view taken from a helicopter of SR.N2 cruising off the Needles. This clearly showed that these craft have a majestic bearing all of their own, and equal to anything seen before on land, sea or in the air.

Gad Sir . . .

The following choice item appeared in the *Daily Mirror* of August 10:

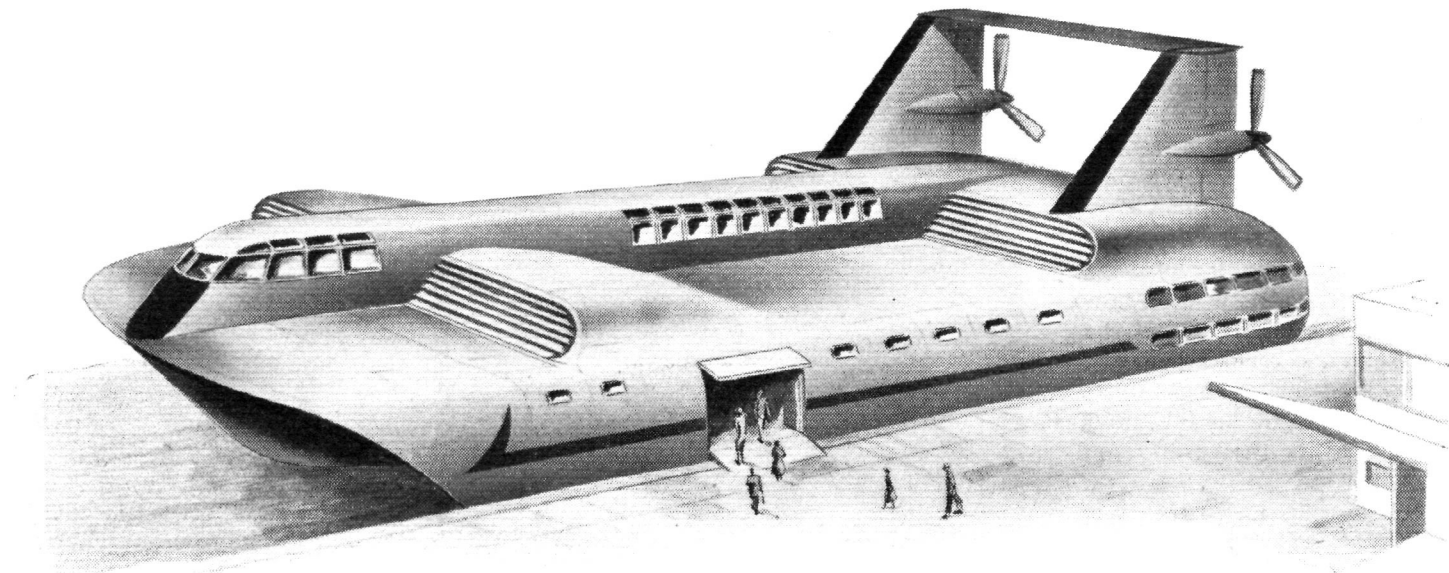
"Yachtsmen racing at Cowes, Isle of Wight, angrily waved their fists yesterday as the SR.N2 Hovercraft churned past them on trials.

"Many of the yachts lost their race positions as they scurried out of the way.

"One skipper said later: 'I was seething. But there was nothing I could do but change course.'

"A spokesman for the makers of SR.N2, the Saunders-Roe division of Westland Aircraft, said: 'Essential trials must go on—even if it is Cowes Week.'"

Prospect: This sketch of a Douglas project for a large passenger-carrying craft was specially prepared by an Air-Cushion Vehicles staff artist for a Television Wales and West programme, during the course of which reference was made to this new journal



crossed; VA-3 has an all-up weight of only 24,500lb.

All had gone so smoothly up to this point that it was perhaps inevitable that rough water should lie ahead.

By April 12 VA-3 had lifted off for the first time; and the control system was obviously a success. Discussions concerning the Permit to Fly were going well between Vickers and the ARB; steady, if rather slow progress, was being made with the Ministries of Aviation and Transport about the exemption clauses; and a BUA manager, Mr R. S. Harfitt, had been appointed to take on-the-spot charge of the commercial side of the operation. A steady flow of bookings began to reach Piccadilly long before the list was officially opened.

On the other side of the coin, the four Turmo 603s which lift and propel VA-3 proved to be unexpectedly noisy. This at once became the subject of anxious debate, since the use of Hoylake as an operating base presupposed that the noise level would be acceptable. And as if to echo these doubts and worries dissentient voices then began to be raised in the town on the score of nuisance, with the result that the council, who had believed that they were contributing to the national interest by agreeing to a Hovercraft service on their

doorstep, came in for sharp criticism from some of their ratepayers.

To determine the depth of these feelings the Hoylake Council called a public meeting at the end of May. Mr Seton-Winton outlined British United's aims in operating a Hovercraft service, and Mr Colquhoun described the proposed operation itself. From the questions which followed it became clear that 95 per cent of the residents were in favour, but there remained a minority who strongly opposed the service, largely on the grounds that Hoylake might be exposed to a flood of visitors.

British United and Vickers agreed that these objections to the service could not be ignored, and reluctantly decided to find a suitable beach elsewhere. From the early survey of New Brighton, Wallasey was an obvious possibility, and a suitable beach, for the use of which local-authority approval was readily given, was found without great difficulty. Although access to Hoylake is better, operationally there is little difference, and it was between Wallasey and Rhyl that the world's first scheduled Hovercraft service began operation on July 20, 1962.

When these words appear, the service will have a few weeks further to run. It

has already been demonstrated that VA-3 can operate comfortably within the 25-minute scheduled block time, for six round trips a day, proposed nine months ago. There have been cancellations, of course, due in about equal measure to weather and to technical teething problems. The latter have been accentuated by operating a deliberately tight schedule with a solitary vehicle, with non-series engines and components. When weather delays have occurred, it has generally been obvious that conditions were unacceptable for any type of sea crossing. As the operation shakes down, regularity is improving. VA-3's noise level was much reduced before it entered service, and the ride is agreed to be pleasant.

Full records are being kept by British United, by Vickers-Amstrongs and by British Petroleum so that the lessons of a unique operation can subsequently be assessed. It would be premature to suggest now how this information will eventually be used, but enough should certainly be learned to provide answers to the four reasons given earlier for operating an experimental service. And whatever the results, the Dee Estuary operation should bring ten steps nearer the first firm specification written by an operator for a Hovercraft manufacturer.

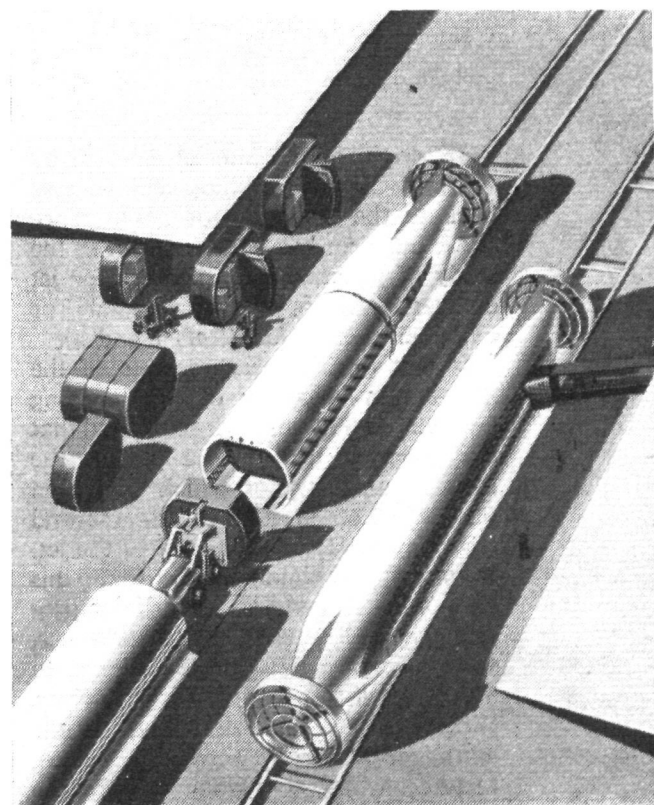
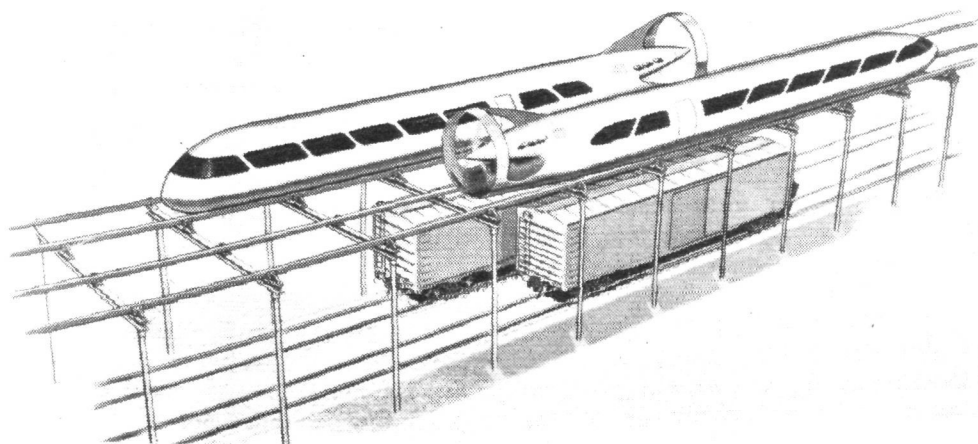
Levacar

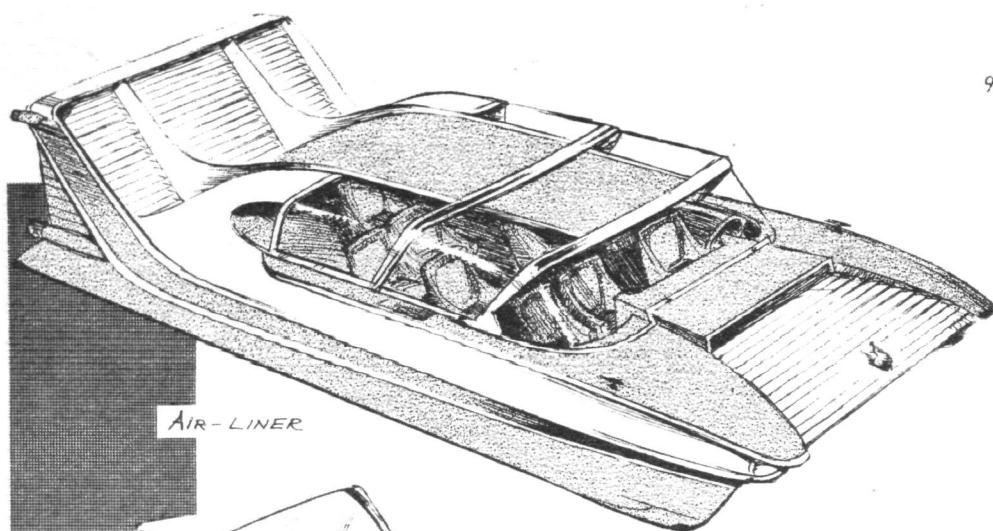
THE "railroad station of the future" depicted on the right is seen with two Ford Levacar vehicles. On the left track a freight-carrier is separated so that specially designed containers can be loaded. On the other track passengers board a 200-passenger vehicle

via a telescopic ramp. Below is an impression of how Levacar tracks could be elevated to run above conventional rolling stock.

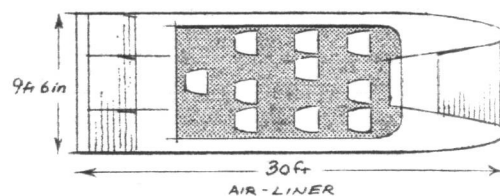
The Levacar would ride on a thin film of air over flat-topped, square-section rails at speeds up to 500 m.p.h.

Impressions of the Ford Levacar system for passengers and freight

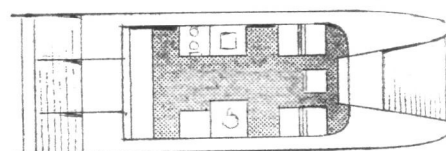




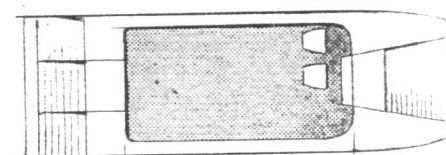
AIR-LINER



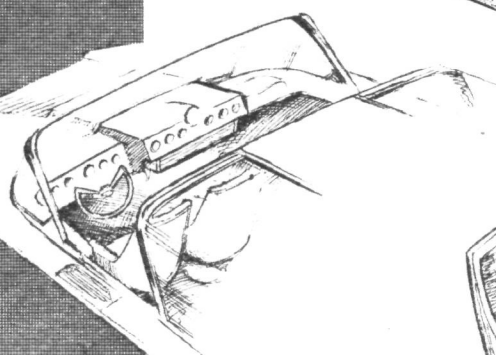
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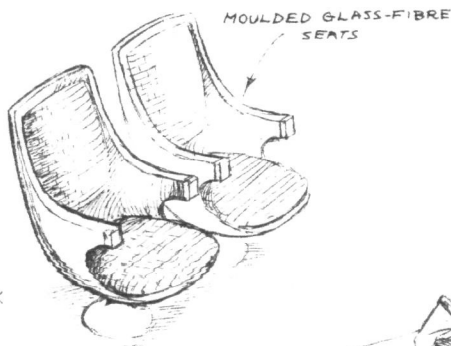
AIR-SPORT



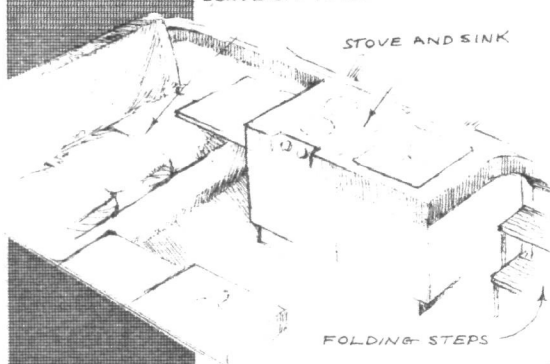
AIR-CARRIER



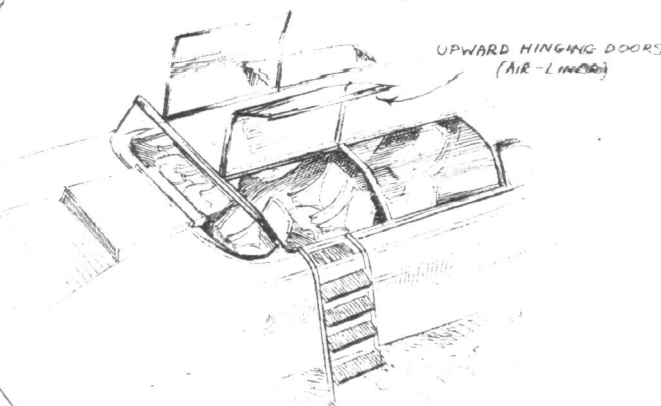
CONVERTS TO BUNKS



MOULDED GLASS-FIBRE SEATS



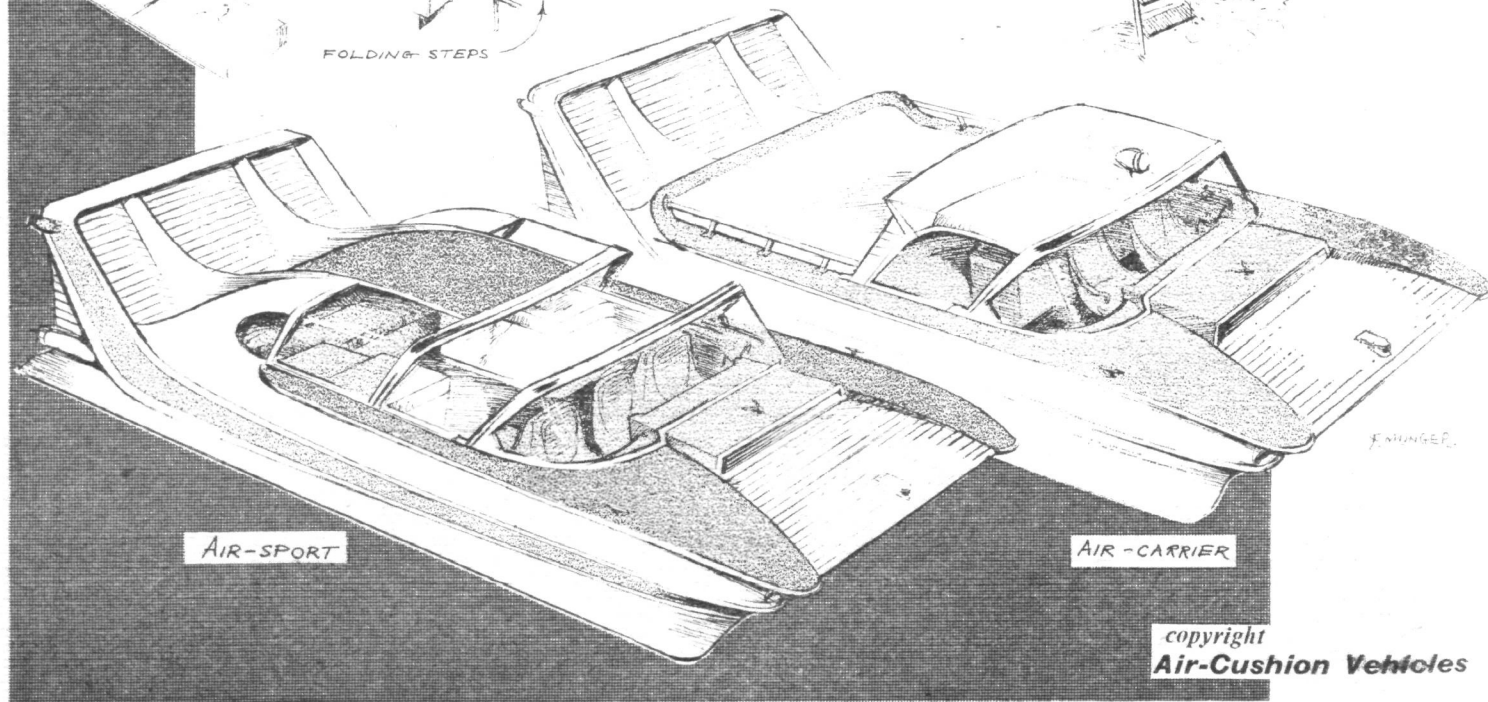
STOVE AND SINK



UPWARD HINGING DOORS (AIR-LINER)



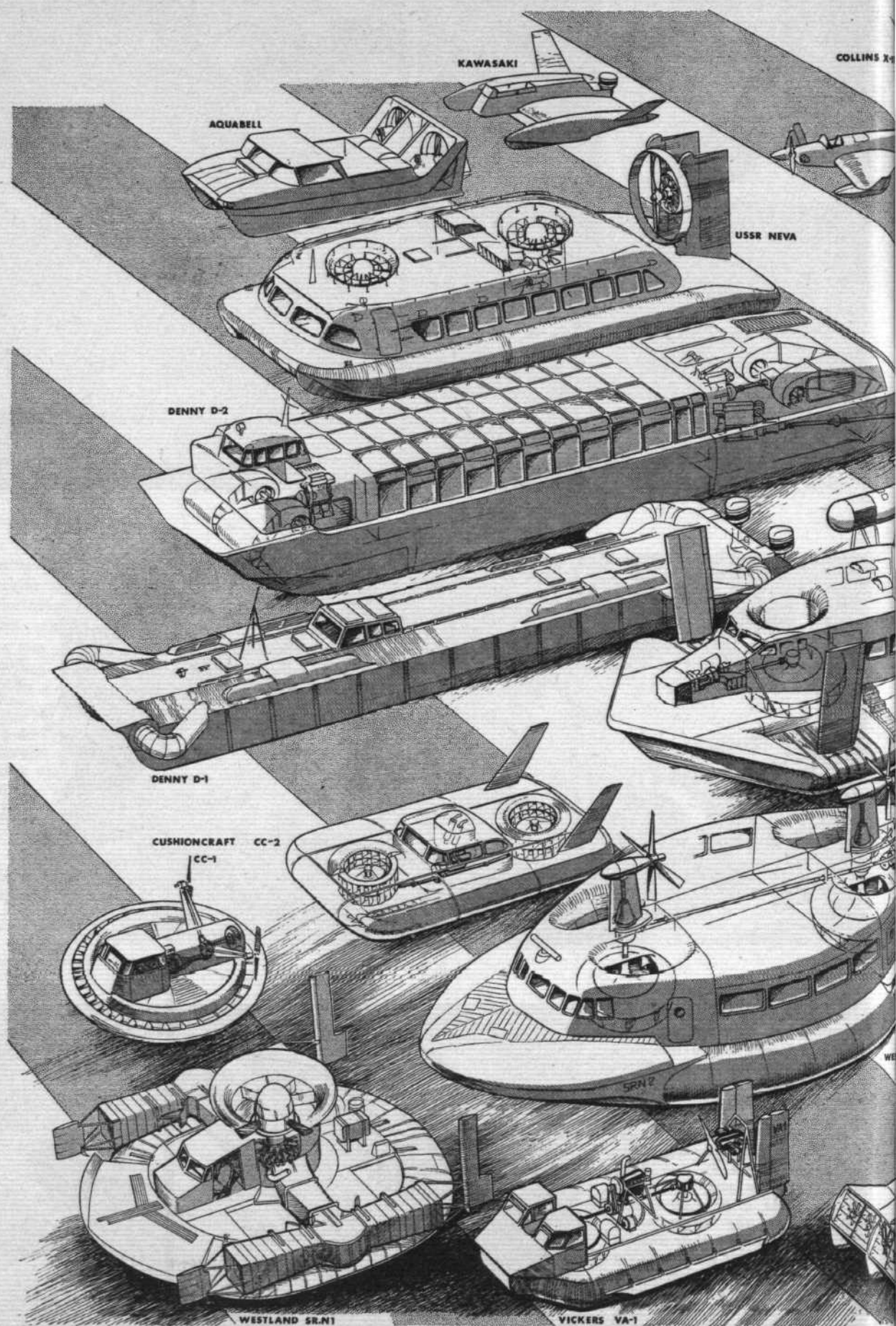
FOLDING STEPS



AIR-SPORT

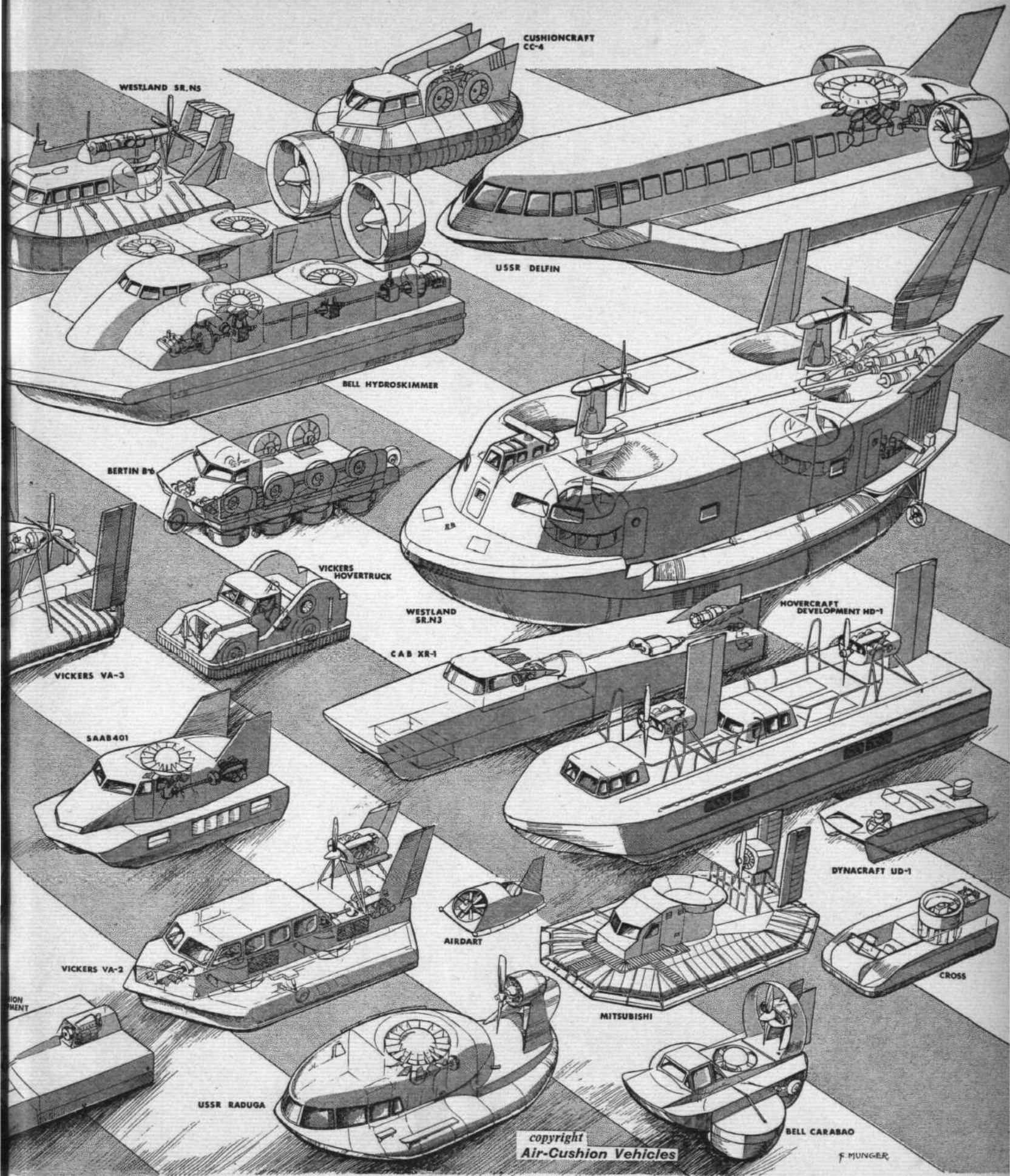
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copyright
Air-Cushion Vehicles



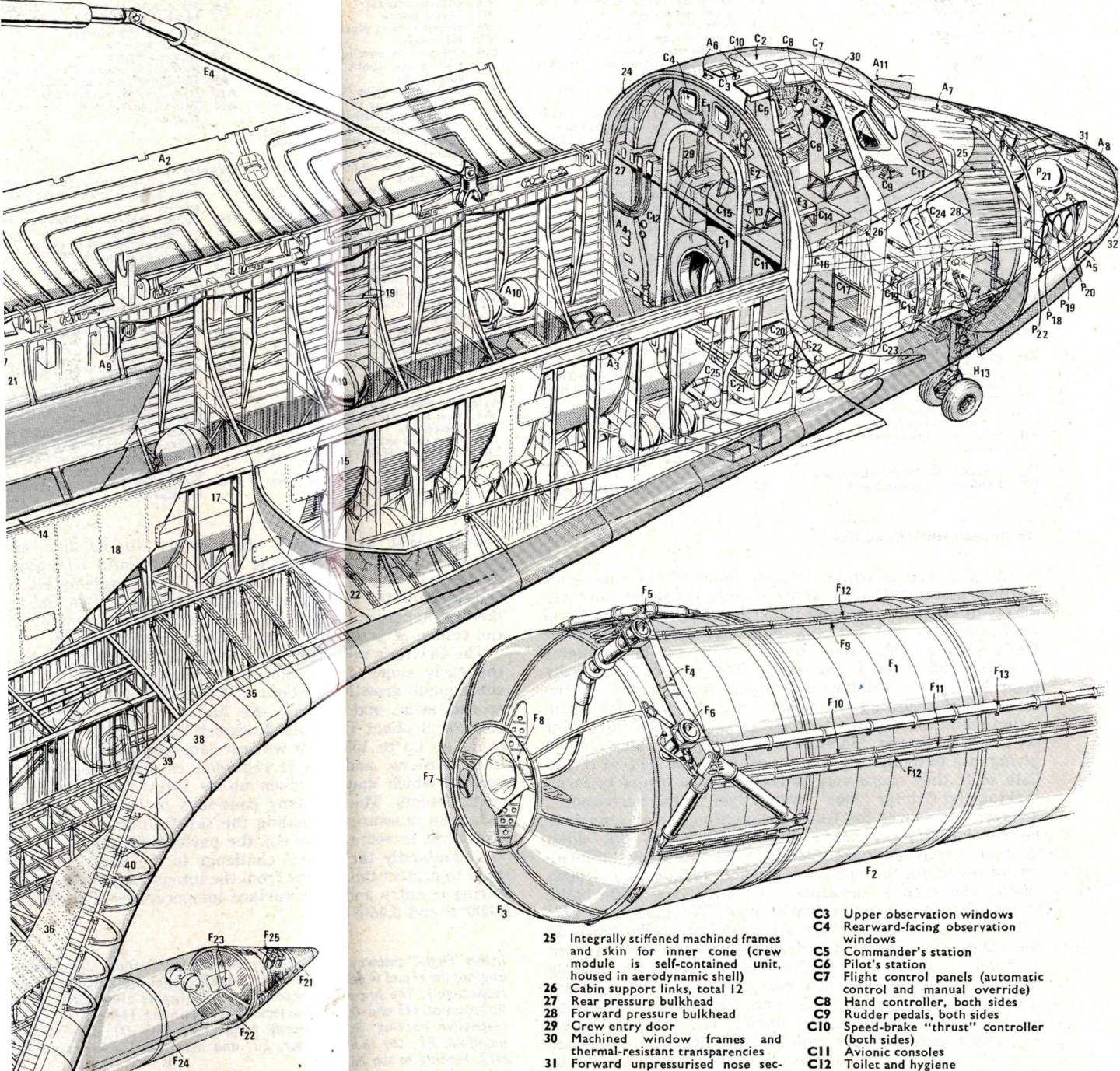
In this unique perspective rendering Frank Munger shows ACV development at a glance. All vehicles are shown in their original form and to a common scale. The dark bands—20ft wide—indicate scale and approximate time base

Air-Cushion Vehicles: *PROGRE*



© Iliffe Transport Publications Ltd, 1964

FROM SR.N1 TO THE PRESENT



KEY

Structure and general

- 1 Two-spar fin torsion box, integrally stiffened skin panels
- 2 Fin base rib, integrally machined
- 3 Multi-bolt fin/fuselage attachment fittings
- 4 Engine support/thrust structure
- 5 Main engine thrust and fin support cant frame, integrally machined
- 6 Shoulder longeron

- 7 Wing spar carry-through structure
- 8 Upper fuselage attachment fitting, also used for hoist attachment
- 9 Upper thrust beams, titanium machined with boron epoxy-reinforced welded-on end fittings
- 10 Lower thrust beams
- 11 Machined and diffusion-bonded titanium bracing structure
- 12 Keel beams
- 13 Aluminium honeycomb heat-shield, thermally insulated
- 14 Mid-fuselage payload bay shoulder longeron
- 15 Electrical cable tray
- 16 Machined, integrally stiffened frames
- 17 Between-frame machined skin stiffeners
- 18 Integrally stiffened aluminium skin panels
- 19 Truss bracing
- 20 Payload bay wing carry-through structure
- 21 Payload bay lining insulation panels
- 22 Payload-bay door, conventional skin and stringer construction (two doors, four panels)
- 23 Radiator panels (two per side)
- 24 Forward fuselage crew module

- 25 Integrally stiffened machined frames and skin for inner cone (crew module is self-contained unit, housed in aerodynamic shell)
- 26 Cabin support links, total 12
- 27 Rear pressure bulkhead
- 28 Forward pressure bulkhead
- 29 Crew entry door
- 30 Machined window frames and thermal-resistant transparencies
- 31 Forward unpressurised nose section
- 32 Reinforced carbon-carbon nose-cap
- 33 Wing/fuselage multi-bolt attachment fittings
- 34 Corrugated-web wing spars
- 35 Built-up, multi-braced and capped wing ribs
- 36 Rivetted stringer, upper and lower wing-skin panels
- 37 Wing/fuselage "stub" structure (electrical and hydraulic connection panels)
- 38 Detachable leading-edge structure, reinforced carbon-carbon skin panels
- 39 Leading-edge access panels (upper and lower)
- 40 Heat-resisting surface insulation along entire leading-edge spar, with built-in thermal barrier
- 41 Sliding elevon shrouds, also give access to elevon controls and jacks
- 42 Entire structure covered in HRSI and LRSI tiles

Environmental control and life support

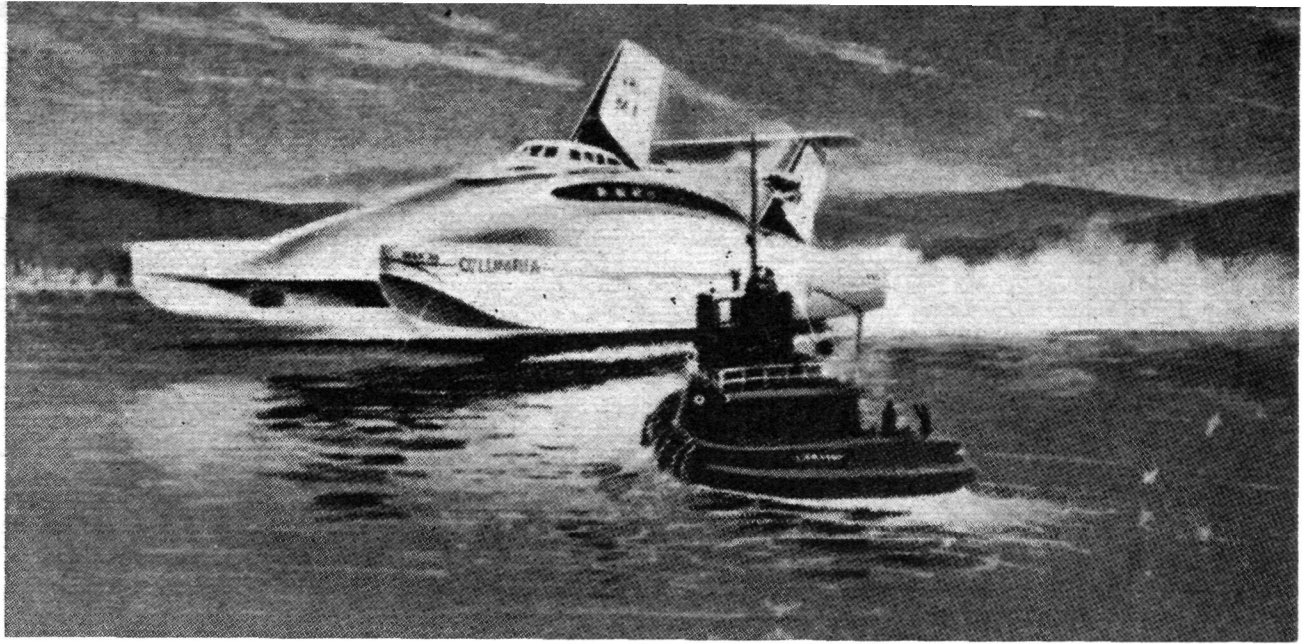
- C1 Access door to payload bay or Spacelab when carried
- C2 Emergency exit, first two Orbiters only

- C3 Upper observation windows
- C4 Rearward-facing observation windows
- C5 Commander's station
- C6 Pilot's station
- C7 Flight control panels (automatic control and manual override)
- C8 Hand controller, both sides
- C9 Rudder pedals, both sides
- C10 Speed-brake "thrust" controller (both sides)
- C11 Avionic consoles
- C12 Toilet and hygiene
- C13 Galley
- C14 Access via floor hatch to lower deck, both sides
- C15 Airlock
- C16 Ladder to lower deck
- C17 Four-berth sleeping bunks
- C18 Cabin heat-exchanger and water separator
- C19 Fan
- C20 Waste-water tanks
- C21 Drinking and domestic water tanks
- C22 Avionics-bay heat-exchanger and fan
- C23 Avionics and instrument cooling ducts
- C24 Return-air ducts to cabin fans
- C25 Capsule and payload-bay venting ducts (nitrogen purged, vented rearwards)

Fuel system

- F1 Hydrogen tank (oxygen tank forward)
- F2 Integrally stiffened aluminium skin structure supported on frames
- F3 Machined end dome
- F4 Rear external tank/Orbiter attachment cradle

continued overleaf



Artist's impression of "Columbia" at speed

THE 100-KNOT "COLUMBIA"

Especially notable among the papers given at the Hydrofoils and Air-Cushion Vehicles Meeting of the Institute of the Aerospace Sciences in New York on September 17 and 18 was that presented, in edited form, in these pages. Delivered by Mr Scott Rethorst, president of Vehicle Research Corporation, it includes an admirable review of the transport spectrum as well as giving the first information on the surface-effect ship "Columbia."

UNDER SUPPORT of America's Maritime Administration, the Vehicle Research Corporation is currently developing a 100-ton surface-effect ship which will have a cruise speed in excess of 100kt. This ship, the *Columbia*, has been determined to be the minimum economical size surface-effect ship, and therefore appropriate as an operational suitability vehicle.

This paper examines the position and potential of the surface-effect ship within the overall transportation spectrum, and formulates a design philosophy for a vehicle which will best fulfil this potential. The configuration of *Columbia* is described and its performance outlined, showing a potential major advance in marine transportation.

Transportation Spectrum The profusion of vehicles now developing from our exploding technology encourages some form of classification to render order out of the confusion. It is particularly useful to place in order such

vehicles in terms of the physics of transportation.

Fig 1 presents such a classification and also provides a basis for ordering the merit of transportation arrangements.

Two conclusions are apparent. First, one should travel through the least dense medium to minimize drag. Second, one should obtain support against the force of gravity, where feasible, from a high-density medium, in an arrangement involving drag of a less dense medium, since drag to a first order is proportional to the density of the medium. These factors encourage translation on the interface. Such conclusions, however, should be adopted only with careful engineering analysis of all the relevant factors.

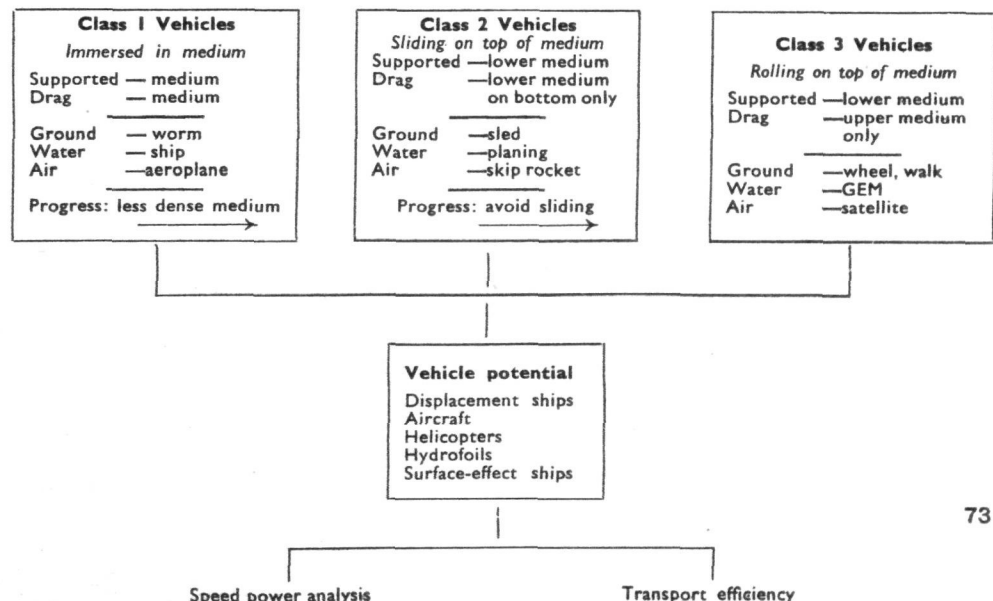
Translation through or immersed in a medium (Class 1 vehicles) involves a situation where a vehicle is both supported by a medium and pays a drag

penalty of translation through this same medium. Examples are: (1) translation through ground, like a worm, (2) translation through water, like a ship, and (3) translation through air, like an aeroplane. Higher speeds for a given power-loading can be obtained by translation through a less dense medium in each case.

Translation by sliding on top of a medium (Class 2 vehicles) presents the advantage of support being provided by the lower medium of greater density, yet paying a drag penalty of the lower medium on the bottom of the vehicle only. Examples are: (1) sliding over ground like a sled, (2) sliding on top of water like a planing boat, and (3) sliding on top of air like a skip rocket. Higher speeds for a given power-loading can again be obtained by sliding on top of a less dense medium.

Translation by rolling on top of a

FIG 1: TRANSPORTATION SPECTRUM



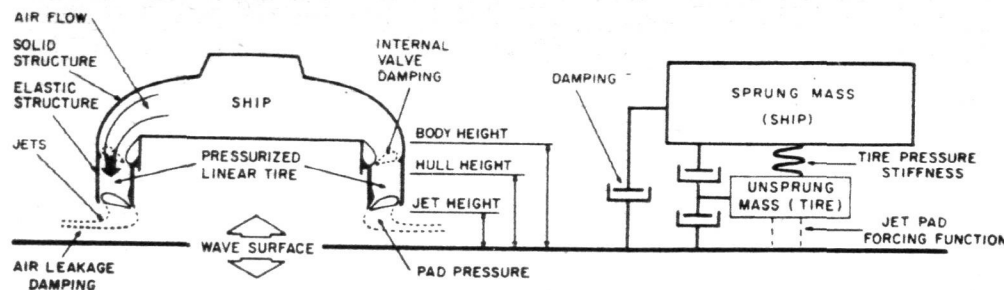


Fig 2 Basic elements of pneumatic suspension system, with mechanical analogy shown at right

THE 100-KNOT "COLUMBIA" ...

medium (Class 3 vehicles) involves a still higher degree of sophistication, achieving superior performance by avoiding sliding altogether. This arrangement provides for the vehicle to be supported by the lower medium of greater density, yet encountering a drag of the upper less dense medium only. Examples are: (1) rolling on top of ground, like a wheel or walking (which is a form of rolling), (2) rolling on top of water, as in a surface-effect ship, and (3) rolling on top of the atmosphere (actually supported by the ground) as in a satellite.

This classification indicates in a general sense avenues of fruitful development for advanced vehicles. These general considerations must be examined more carefully in individual cases for further progress.

Operation on the Interface The general considerations of the foregoing transportation spectrum point towards the advantages of vehicle operation on the interface, where a vehicle has the advantage of support by a dense medium, requiring little or no energy expenditure, and is penalized by the drag of this lower dense medium only on the bottom of the vehicle, and where, in advanced vehicles employing rolling, a drag of the upper less dense medium only is encountered.

The difficulties of such operation on the interface stem primarily from the conditions of the interface itself, such as smoothness and load-carrying ability. Wheeled vehicles, in order to achieve their advantages of rolling, require smooth and strong roadways. Planing boats do best on smooth water. One can walk and run best on a smooth surface. Conversely, the exponential nature of the atmosphere/space interface renders the feasibility of the skip rocket questionable.

Operation near the Interface The difficulties of operation on the interface caused by rough water can hopefully be circumvented by operation *near* rather than *on* the interface. The hydrofoil may be regarded as an arrangement to plane near and *under* the interface, where the water is smooth. It has the advantage of planing whilst tolerating

a certain degree of irregularity of the interface. This analogy is particularly acceptable for a foil which is fully cavitated on the upper surface, and thus may be regarded as planing on its under surface. The hydrofoil then fits in the category of sliding on top of a medium in terms of the previous transportation spectrum, where support is obtained from the lower, more dense, medium, namely the water, and drag of this lower medium is encountered on the bottom only, in this case the bottom of the foil itself.

Operation near the interface may also be accomplished *above* the interface. This is the category of the surface-effect ship. Here support is provided by the lower, more dense, medium, either ground or water, and drag is involved only by the less dense air above. Frictional drag is to a first order proportional to the density of the medium, and water is about 800 times as dense as air. Since support is provided entirely by the more dense medium, and drag is involved only by the upper medium of air, the surface-effect ship falls into the category of Class 3 vehicles. The air in the pressure bubble or pressure field underneath the GEM transmits the weight of the vehicle directly to the dense water surface, yet supports the vehicle above this surface, and in so doing avoids any sliding friction on the water. In this context, the surface-effect ship can be considered as rolling on top of the medium.

This arrangement of support through a pressurized field of air has the advantage of tolerating a certain degree of irregularity and low load-carrying ability of the interface itself by distribution

Air-Cushion Vehicles
FLIGHT International supplement,
25 October 1962

of the weight of the vehicle uniformly over such an irregular interface surface. The problem of the surface-effect ship is to maximize this supporting ability with the greatest tolerance towards irregularity of the interface itself. This essential requirement defines the design philosophy that must be implemented for a successful surface-effect ship.

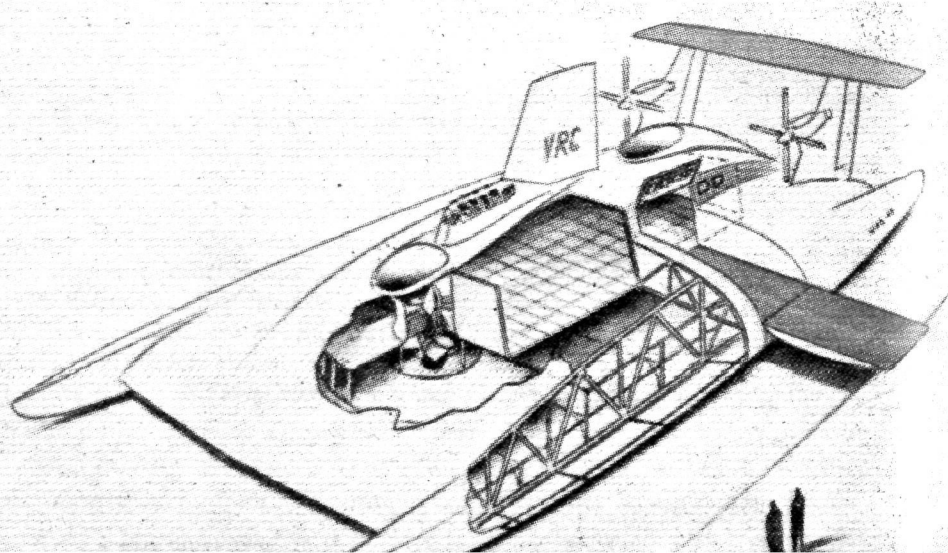
Design Philosophy Power required for the lift of a surface-effect ship operating in the annular jet regime on a conventional pressure bubble at the heights of interest increases with the height of the peripheral jet nozzle above the interface. Power required for lift in the channel-flow regime at the heights of interest is approximately halved, because the jet is required only along the sides, and then only to screen the bottom lift. This aerodynamic lift is only slightly dependent upon the body height above the surface. Hence it is desirable to have the body located high above the waves, and the jet outlets close to the interface. It is therefore clear that the jet outlet should be as close to the interface as possible to minimize this power requirement. The vehicle body, on the other hand, should be at a sufficient height above the interface to avoid the surface irregularities, namely the waves, and so provide a smooth ride with minimum impact-loads.

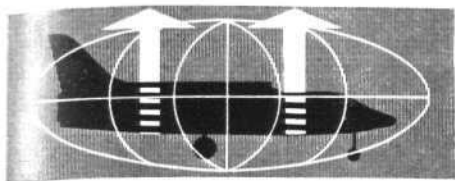
These conflicting requirements can be met by an arrangement providing one or more hulls (designed hydrodynamically for cutting through the waves and structurally for wave impact) equipped with flexible members on their underside, arranged to emit the peripheral jet close to the varying interface surface.

The primary body of the vehicle could then be mounted on top of such special-purpose hulls. The body itself, carrying the cargo and passengers, would thus in effect be located above the extremes of the waves, riding level and above the wave system.

These requirements for a vehicle body

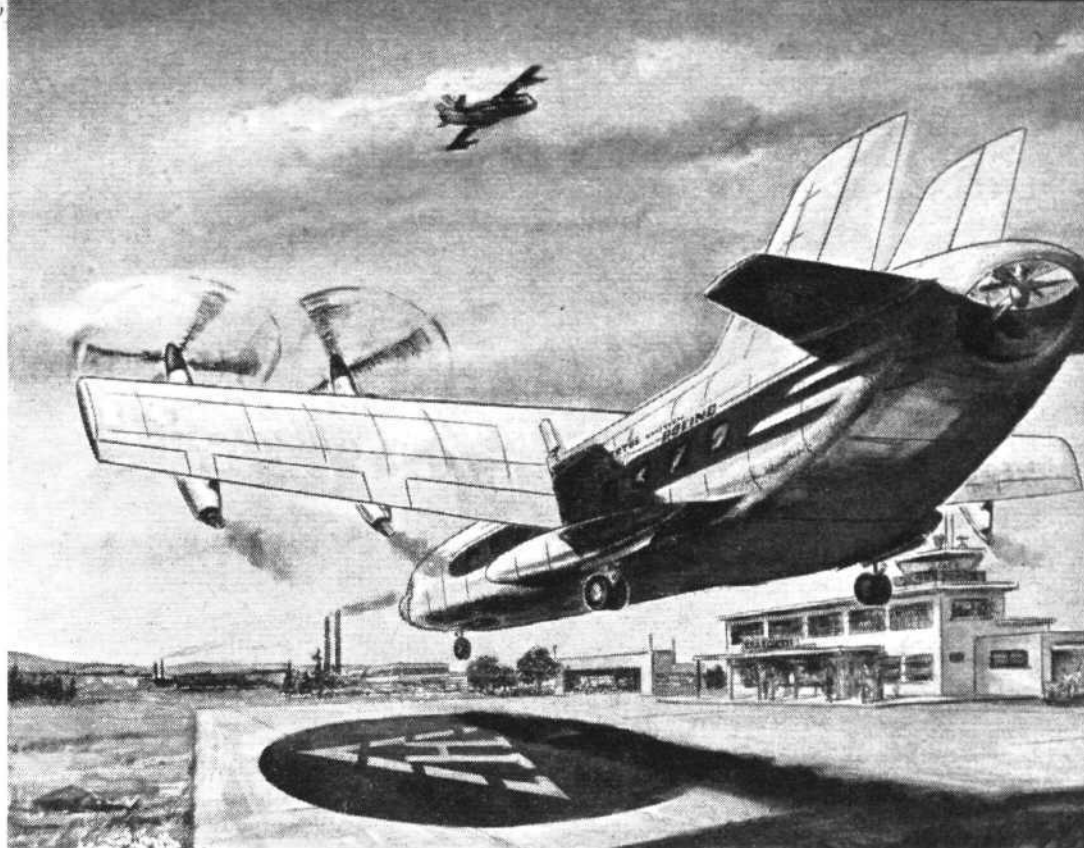
This cutaway drawing illustrates the general arrangement of "Columbia"





VTOL — now or never

BY JOHN W. R. TAYLOR



THE whole future of VTOL flight may depend on what happens in the next twelve months. After years of patient, costly development and experiment, we have in the Vertol 107 and Sikorsky S-61 a pair of big commercial helicopters with operating economics that no longer look like something out of *Alice in Wonderland*. A few years later is the Westland Rotodyne, which should be better still.

It is not enough for the handful of established helicopter airlines like New York Airways, Los Angeles Airways and Chicago Helicopter Airways to order a total of fewer than 20 S-61s and 107s. If we are ever to have a network of short-haul helicopter services on a worldwide basis, some bold and expensive decisions must be taken now; and this concerns Britain most of all, for no city on earth is better placed than London as the centre for such a network.

The faint-hearted will protest that there is no proof that these new helicopters can be operated efficiently and without vast subsidies. They point to other forms of VTOL aircraft such as tilt-wing and fan-lift aeroplanes, or even the Griffith proposal for a supersonic jet-lift airliner, and ask whether it might not be wiser to pour all available funds into the development of these potentially better projects.

Such people would never have dreamed of opening the pioneer cross-Channel air services with D.H.9s and H.P.O/400s in August 1919. They would have wanted proof that the operations were feasible, and Britain would have been left behind. Nor would they have contemplated ordering the incomparably successful H.P.42s in 1929, in case somebody produced a better aeroplane—perhaps one of the new-fangled monoplanes—within ten years.

In those days, of course, operators did not have to think in terms of ten years. The revolutionary Short Empire flying-boats were ordered in 1935. The prototype flew on July 4, 1936, and entered regular passenger service less than four months later, on October 31—a total development period of under two years.

If this pace of development could be matched by modern helicopters and VTOL aircraft, a wait-and-see attitude might be justified. But a glance at the record reveals a very different picture.

It is nearly ten years since Fairey Aviation began design work on the Rotodyne. The prototype flew three-and-a-half years ago, on November 6, 1957. If, as should have happened long ago, sufficient money is put into the development programme by the Government, the Rotodyne may be ready for service by the mid-sixties—a total development period of some 15 years.

It can be claimed that the Rotodyne is revolutionary; but so are all the alternative types of VTOL aircraft. Its design has been improved tremendously since the early fifties; yet what worthwhile modern transport aircraft does not show improvement between the project stage and operational use? Its development *could* have been speeded by Government subsidy; but how many modern British aircraft, civil or military, have been able to progress from design to production without perpetual policy changes, specification changes and threats of imminent cancellation? So there is no reason to feel that 15 years is an unduly long period in which to expect a VTOL aircraft to reach maturity.

This time-scale must be borne in mind whenever VTOL operations are contemplated. It is quite wrong to imply, as many people

do, that the Rotodyne is so close behind the Vertol 107 or Sikorsky S-61 as to be considered contemporary; or that the other forms of VTOL aeroplane are within such easy reach that the stage of development represented by the Rotodyne could be omitted. Even less realistic is the familiar suggestion that Britain should take another mighty leap forward, by-passing the "conventional" supersonic airliner and producing a VTOL supersonic airliner of the Griffith jet-lift type by the end of the 1960s.

Let us not say that this would be impossible, for our aircraft industry is second to none when given its head; but post-war history proves that such speedy development is extremely improbable, and that it is potentially disastrous to stake everything on a mighty technological leap in the dark.

Already the prediction that all major airlines will be flying supersonic airliners by the late 1960s is beginning to appear hasty. Delegates to IATA's 14th Technical Conference at Montreal a couple of weeks ago were inclined to think in terms of the 1970s. Several of the more hard-headed favour the late 1970s now that work on the North American B-70 Mach 3 bomber has been slowed down.

It would hardly be reasonable to expect a VTOL supersonic airliner to be ready for service before a "conventional" type. So, while doing everything possible to maintain the leadership given us by the Short SC.1 and, in a different field, the Hawker P.1127, it is time for this country to work out—and stick to—a realistic policy on VTOL flight for the next ten years.

A Policy for BEA British European Airways were among the pioneers of helicopter operation, their early achievements including the world's first helicopter night-mail service (on February 21, 1949) and the first regular passenger services, in June 1950. There are plenty of indications that they would like to get on with the job of building up a network of helicopter passenger services in and from the UK, but that they are being hampered by lack of imagination and courage in those who hold the purse-strings.

A Penzance-Scilly service operated with a commercial development of the Belvedere, as has been suggested, would be a step in the right direction, but a hardly adequate one. Even if the aircraft equalled the Vertol 107 and Sikorsky S-61 in efficiency, it would not be available as quickly and would hardly attract sufficient overseas interest to justify the cost of its development. Nor is the Penzance-Scilly route, by itself, worthy of one of Britain's national airlines, which had the courage in the 1950s to set the pace in turbine transport operation.

We should admit we have nothing to compare with the Vertol and Sikorsky designs at the present time, and order a large enough quantity of one of them for BEA to open a worthwhile network of passenger services based on London.

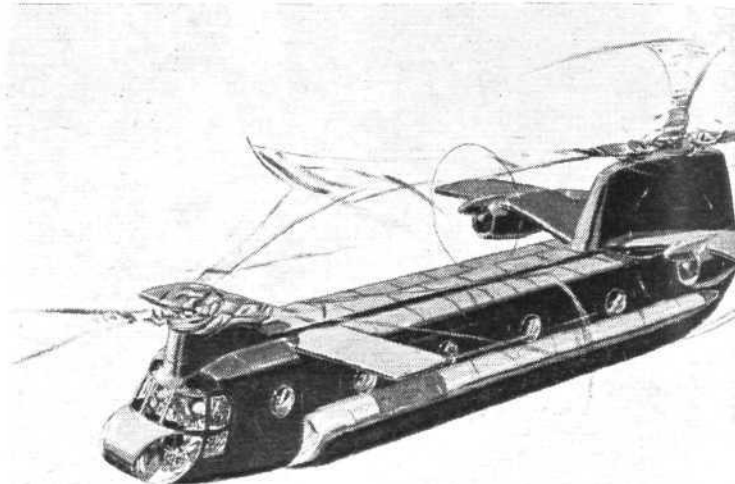
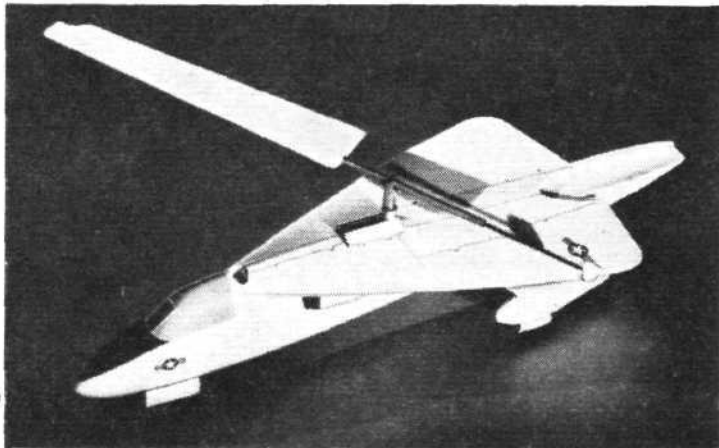
Not having seen the S-61, it would be invidious to state a preference for either of these US helicopters. Both are basically 25-seaters and both are powered by General Electric CT58 shaft-turbines.

In the heading picture: Vertol take a look ahead towards tilt-wing commercial transports powered by four 2,650 h.p. T64 engines

Wind-tunnel model of a projected assault transport built round two Chance Vought ADAM (Air Deflection And Modulation) propulsion/control packages. Four J60 turbojets above the wing drive ducted fans with air-deflection nozzles

Sikorsky S-58s. If they bought S-61s or Vertol 107s, a pooling arrangement with BEA would offer passengers a closely knit network of city-centre services linking London with Paris, Brussels, Antwerp, Lille, Rotterdam, Liège, Maastricht, Cologne, Bonn, Eindhoven, Duisburg and Dortmund. BEA would stand to benefit from the unrivalled operating experience acquired by Sabena since they opened the world's first international helicopter passenger services in September 1953.

There is little doubt that a scheme of this kind is practicable today, and something must be done soon if BEA are to maintain their reputation as a helicopter-minded airline. The problem of providing a heliport in London remains, and it is one we should be foolish to dismiss lightly. The Westland Heliport at Battersea, while deserving all praise for the initiative that brought it into being, is not in the right place for regular international passenger services.



Left, a model of Sikorsky's S-57 tactical fighter design-study, with retractable rotor. Right, the 227kt Compound Chinook proposed by Boeing-Vertol

VTOL—now or never...

This means that dollars could be saved by installing DH Gnomes, which are the same engines built under licence in the UK. The Vertol 107 should offer the advantage of greater c.g. travel, because of its tandem-rotor layout. The absence of a high-speed tail rotor might also make it less noisy—and this could well be a critical factor in considering city-centre operations in London. On the other hand, the close links between Sikorsky and Westland might add to the attractions of the S-61.

Both types would make possible non-stop services from London to Paris, Brussels, Rotterdam and the Channel Islands, and to Manchester and numerous other cities in Britain. Prestige-wise, and because heavy traffic already exists on the routes, it would appear preferable to start with the London - Paris - Brussels - Rotterdam network. Duplication with Sabena's well-established helicopter services could be avoided by pooling arrangements of the kind that are now normal on fixed-wing services. Furthermore, Sabena themselves must be in the market for a replacement for their

An interim answer would be to follow the example of the Port of New York Authority in providing city-centre heliports on piers over the river. One alternative would be a semi-mobile base of the barge type, which could be moved experimentally from point to point until a site was found that offered a good operating environment for both the aircraft and, in terms of noise, for those living and working in the vicinity.

What would be the prospects for a cross-Channel helicopter network of this type, operating from a heliport near the City of London? The big attraction, of course, would be the elimination of city-centre-to-airport journeys at each end, leading to a reduction of some 50 per cent in overall travelling time even in comparison with the latest jet airliner schedules. Fares would, inevitably, be higher; but the increase would be offset by the saving in airport coach or taxi fares and in time. Businessmen could quite easily fly from London to Paris in the morning, spend several hours in conference and return in the late afternoon—which may seem an awful waste of a trip to the Gay City, but does demonstrate the possibilities of such a service.

Lessons from New York For the businessman in a hurry, fares are often a secondary consideration. This point was made by Sir Ralph Cochrane in February during his Brancker Memorial Lecture, when he remarked that:—

"As an example of costs, Mr Robert L. Cummings, President of New York Airways, spoke in a recent paper of a fare of 48 cents (3s 5d) a seat-mile, but indicated that nevertheless they expected to be carrying a million passengers by 1963, with a rapid increase thereafter. That is an example of the amount which passengers are prepared to pay if they can be saved the time necessary to force their way into the city from an aerodrome outside."

The very short stages over which New York Airways fly most of their services are in contrast to the 200-mile cross-Channel routes considered above for BEA; but much can be learned from the New York operations, particularly in respect of aircraft reliability.

Figures just issued show that the company's present fleet of five Vertol 44s, in service less than three years, have each logged more

US manufacturers regard the compound helicopter, with off-loaded rotor, as an essential step between the pure helicopter and future V^{OL} transports for passenger and freight work

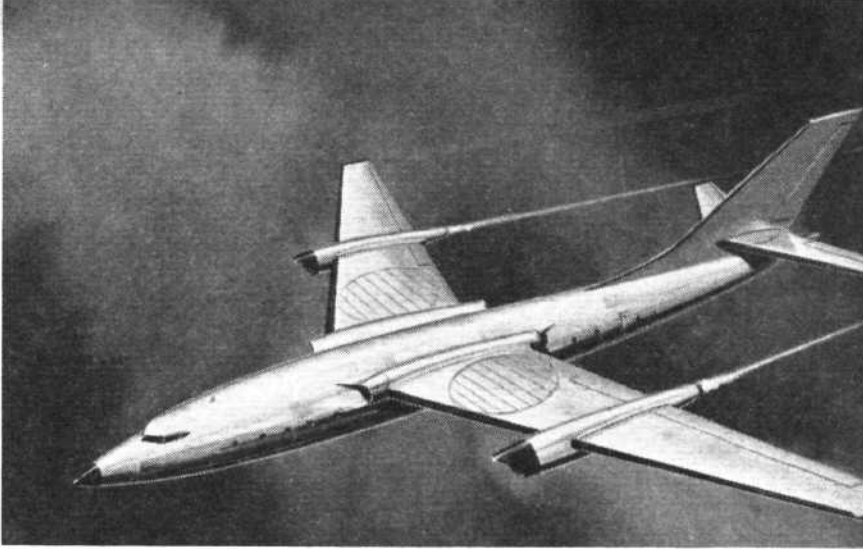


than 4,000 flying hours, with a total flight time of more than 22,000hr. During 1960 these aircraft made over 40,000 scheduled flights, of an average duration of 12min. Excluding delays and cancellations caused by weather, the single-engined Model 44s departed within five minutes of the scheduled time on 98.8 per cent of the flights.

Soon the 15-passenger Model 44s will be replaced by a new fleet of 25-passenger Vertol 107 Model IIs, with all-weather capability and all the advantages of a twin-turbine installation over the single piston-engine of the earlier type. It is this initial re-equipment that enables Mr Cummings to look forward to one million passengers annually by 1963, compared with a total of something over half-a-million in the past nine years.

Furthermore, the 107 Model II represents only the start of the development of this aircraft. In the design stages is a cleaned-up version, the Model VI, with retractable landing gear, extended and pointed rear fuselage, rotor hub fairings and wider-chord blades, which will offer a cruising speed of 175kt compared with the 135kt of the Model II.

Already, a larger and more advanced version of the 107 is in production for the US Army as the Chinook. A commercial coun-



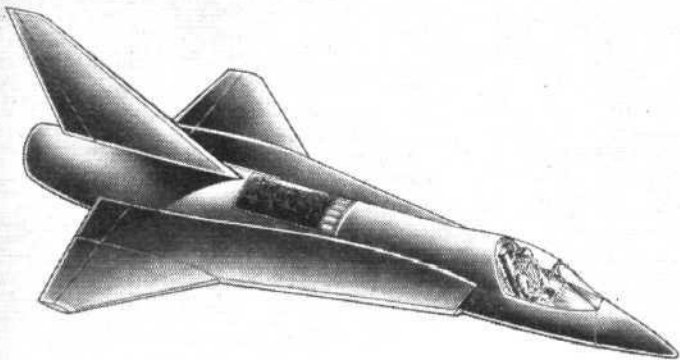
This Ryan project for a Vertifan-equipped jet airliner would offer VTOL, high cruising speed, and hovering ability. Air deflection vanes above and below the tip-driven fans close to seal the wing in forward flight

Comparative Performance and d.o.c. per Available Seat-n.m. at 100 n.m. Stage-length (Figures by Vertol)

Aircraft	107 Model II	107 Model VI	Chinook	Compound Helicopter	Tilt wing	F-27
Engines and h.p.	(2) T58/1,250	(2) T58/1,400	(2) T64/2,650	(2) T64/2,650	(4) T64/2,650	(2) RDa.6/1,720
Gross Weight* (lb)	18,450	19,130	32,000	33,800	45,000	35,700
Weight empty (E) (lb)	11,210	11,925	19,392	22,450	27,400	22,237
Fixed useful load (lb)	634	634	646	646	706	917
Fuel (100 n.m. + 30min cruise) (lb) ...	1,606	1,550	2,525	2,105	3,620	1,900
Payload/Passengers (P) (lb/no)	5,000/25	5,025/25	9,437/47	8,599/43	13,274/66	10,646/40†
Cruising speed (kt)	138	176	160	227	327	220
Blockspeed (with 10kt headwind) (Vb) (kt)	123	157	143	202	287	138
PVb/E (kt)	55	66	70	77	140	86
Direct operating cost per seat-mile (c) ...	7.33	6.53	5.49	4.86	3.50	3.33

* Based on one engine out, 70° F at sea level. † Space limited.

For over six years Short Bros & Harland Ltd have been investigating VTOL possibilities. As a background to the SC.1 are numerous studies ranging from light fighters to big supersonic aircraft. Below is a strike fighter design directly derived from the SC.1



terpart has been projected, with 48 seats and a cruising speed of 160kt. Even more attractive is a proposed "compound" version, with stub wings fore and aft and a twin-turboprop powerplant. By converting to autogyro configuration in cruising flight, with the rotors autorotating, it would be able to fly at approximately 230kt.

Cruising speed tells only part of the story. More important in many respects are operating costs. Figures issued by Vertol (see table) show that the 107 Model II has an estimated direct operating cost of 7.33 cents per available seat-nautical-mile over the optimum range of 100 n.m., compared with 6.53 cents for the 107 Model VI, 5.49 cents for the commercial Chinook and 4.86 cents for the Compound Chinook. These costs are put into perspective by a figure of 3.33 cents for the Fairchild F-27 at the same range, which is by no means the optimum for this fixed-wing transport.

Statistics of this kind emphasize the potential importance of the compound helicopter, so it is not altogether surprising that Sikorsky have come to much the same conclusions as Vertol. In a study entitled *The Helicopter as a Competitive Transport Vehicle*, published in the July 1960 issue of the *Journal of the American Helicopter Society*, Ralph B. Lightfoot, Sikorsky's chief engineer, compared the flight characteristics of a modern turbine-powered helicopter and its derivatives with other forms of VTOL aircraft. Using as a basis the requirement to carry 40 passengers for 260 n.m. Mr Lightfoot reached these conclusions:—

"It is found that the downwash characteristics of high disc-loading aircraft such as the lift-fan and (commercial) tilt-wing are prohibitive,

This drawing by a Sikorsky artist envisages crane helicopters picking up passenger-pods from a city-centre heliport for delivery to an airport, where they would be set down at the end of the runway and the passengers transferred without delay to waiting airliners



HEADLINES

that number will be sold by the end of the decade.

Further complicating the issue is the question of Airbus Industrie's forthcoming launch of the 130-seat A319. While this is seen as complementary to other Airbus offerings, and not competing with the regional jets, its launch will be dependent on the availability of sufficient funds from the partner companies.

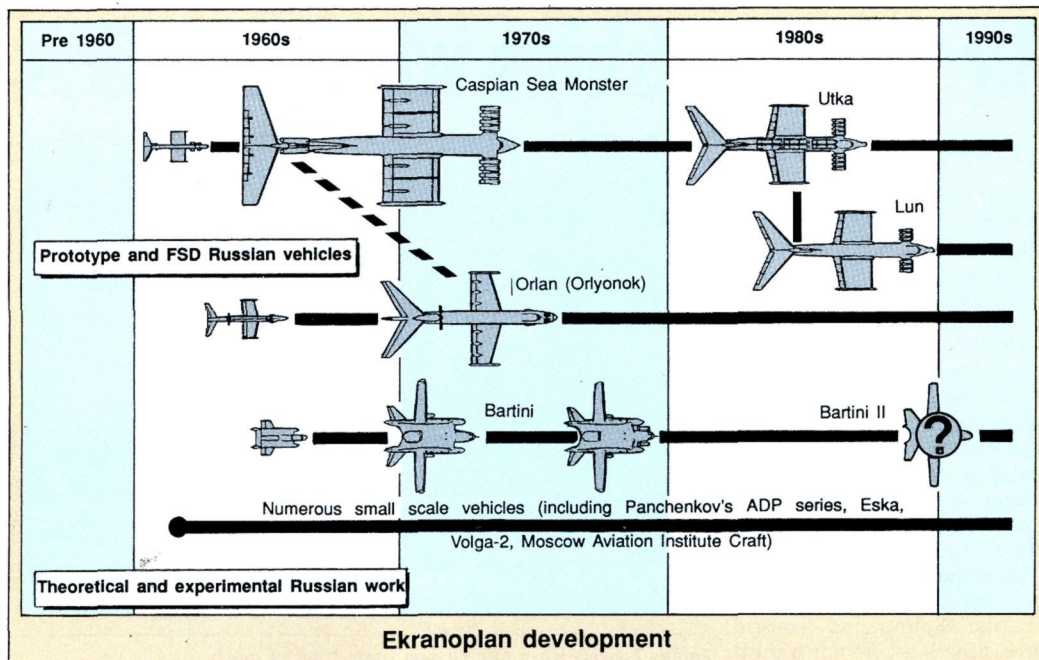
The German Government is already being pressed to help fund the Regioliner programme and its associated engines. The two engine consortia vying for German funding — MTU with Pratt & Whitney and BMW with Rolls-Royce — have already begun exploratory talks on a tie-up of their new programmes.

Airbus says it will fund A319 development internally, but Germany wants final assembly, for which it would have to pay.

A DASA decision in favour of Fokker would be good news for UK aero-engine builder R-R, which has its Tay engine on the Fokker 70 and 100 programmes.

A DASA decision to follow the Fokker edict and abandon the Regioliner agreement would leave Aérospatiale and Alenia without a regional-jet programme, and end the co-operative marketing agreement between the three companies covering their turboprop and jet aircraft.

See Business P 20



USA joins Russia on Wingship

BY MIKE GAINES

The USA and Russia are to co-operate on the development of 5,000t-class wing-in-ground-effect (WIGE) cargo vehicles based on Russian Ekranoplan technology (*Flight International*, 15-21 January).

Aerocon, a Virginia-based company funded by the US De-

fense Advanced Research Projects Agency to explore the use of WIGES for military applications, visited Ekranoplan experts at the Panchenkov and Alekseyev design consortia in January. Both Russian concerns have signed co-operation protocols with Aerocon.

The Alekseyev team, responsible for the huge "Caspian Sea Monster" of the early 1970s and the later Orlyonok series — both of which have flown — has designs better suited to a sea-going craft, says Aerocon president, Steve Hooker, while the Panchenkov designs, named after early Ekranoplan researcher Bartini, appear better suited to a trans-tundra concept. A number of the Alekseyev designers are to visit the USA soon.

The present plan is to set up a new group called the American-Russian Wingship Engineering and Manufacturing Research Centre, sharing bases at Hampton, Virginia and Niizhniy-Novgorod.

Hooker says: "We aim to bring Russian scientists to Hampton and begin a trans-engineering process. We need to translate their concepts into engineering and then into the American engineering convention. We will pay the Russians for hardware used in testing. We

are talking to Lockheed and General Dynamics on structures and Pratt & Whitney and General Electric on engines."

"We think that the 5,000t class is possible, using smart structures. We believe that the Achilles heel would be materials and their joins and fasteners."

The proposed 5,000t military Wingship, powered by 20 large turboprops, would have a 1,500t payload. The cost of development is estimated at \$15 billion and unit cost is \$400 million.

The USA is studying Ekranoplans, which it calls Wingships, for the US Navy's Military Sealift Command as a troop/cargo transport, able to install and support a task force. Russian interest is in a cross-tundra transport.

NEWS IN BRIEF

NEW 146 ORDER

UK carrier Dan-Air has traded its two leased BAe 146-100s against two -300s for delivery in mid-1992. It has agreed to replace the -300s, and also two already in service, with four new Category IIIA landing-system-equipped -300s which will be available next year. It has taken options on two further such aircraft.

Hughes protests Northwest choice

Hughes Aircraft has lodged a protest with Northwest Airlines after the US carrier short-listed rivals GEC Avionics, Rockwell-Collins and Sextant Avionique to develop a head-up guidance system (HGS) for its Boeing 747-200s and McDonnell Douglas DC-10s.

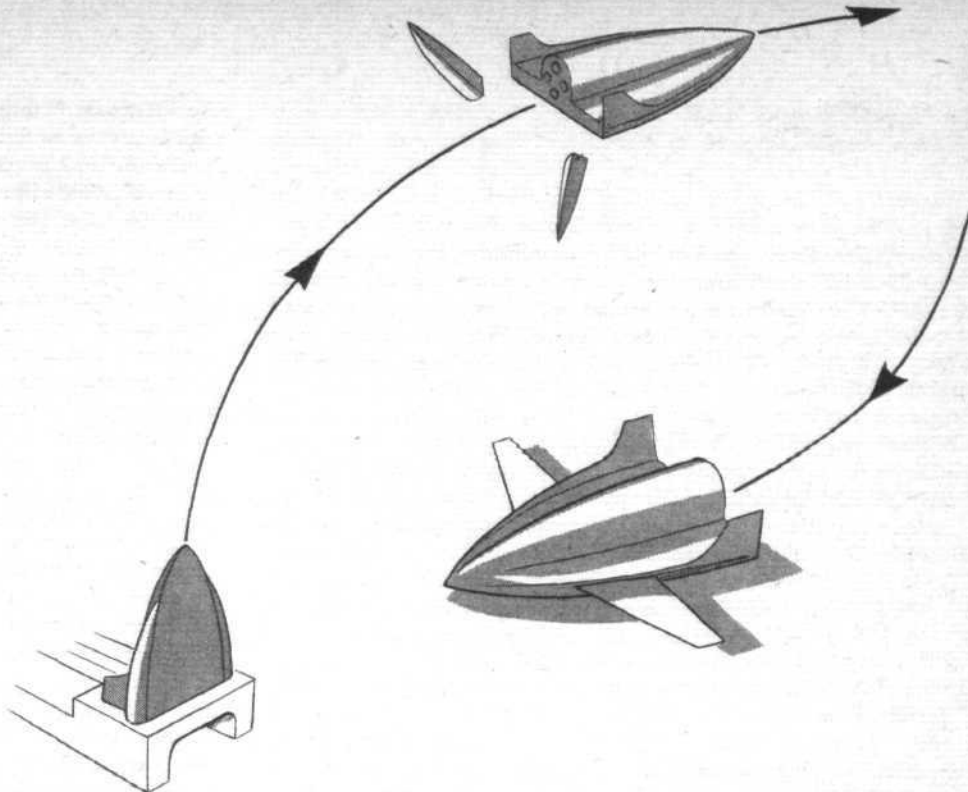
The Hughes protest follows its \$14.5 million acquisition of leading HGS manufacturer Flight Dynamics. The move strengthens Hughes' efforts to develop an autonomous landing guidance system, the company's first venture into commercial avionics, but it failed nevertheless to make the Northwest shortlist. Pricing may have been a factor, competitors suggest.

The shortlisted manufacturers will participate in a five-month

simulator evaluation programme, says Dwayne Edelman, Northwest's manager, flight operations, development technology programmes. The most promising candidate system will be flight-tested and, if successful, will be retrofitted to Northwest's 747s and DC-10s, he says. Evaluation and certification will take 24 months.

Northwest's request for proposals called for a head-up display with the capability to present infra-red or radar runway images, allowing takeoffs and landings in low visibility. Initial certification will be for the head-up guidance system only, Edelman says, with growth to an enhanced vision system combining sensor and display coming later.

Spaceflight



A "Flight" impression of the NASA space shuttle. The 1½-stage vehicle on the launch pad would weigh 600,000lb fully fuelled, and is injected into orbit by a thrust of 750,000lb (both values, incidentally, exactly 10 per cent of those applicable to the Saturn V rocket). The vehicle could deliver a 25,000lb payload to a height of 100 n.m., the external fuel tanks being jettisoned in flight. To provide better lift/drag ratios than present-day lifting bodies (and, consequently, a less critical glide path and more manoeuvrability), small wings, which are retracted for launch, are extended for approach and landing. By this technique the use of sites such as major airports becomes practicable

NASA's BOOST GLIDER PROJECT

In a lecture to the British Interplanetary Society which may well have historic importance, a leading NASA official sets guidelines for new advances in space technology which could revolutionise the commercial future in orbit. His forecasts include the development of factory processes in space. The paper is to be published in full in the BIS magazine "Spaceflight."

NEW THINKING by NASA on the design of re-usable launch systems and space stations was the keynote of a fascinating lecture given by Dr George E. Mueller, Associate Administrator, Manned Space Flight, at a special meeting of the British Interplanetary Society in London on August 10. The speaker was responding to a tribute to NASA and the management of US space programmes by Mr Kenneth W. Gatland, vice-president of the Society, who presented a Certificate of Honorary Fellowship to Dr Mueller in recognition of his outstanding contributions to astronautics.

In reply, Dr Mueller said that although there had indeed been rapid progress in the past seven years since man first ventured from the Earth's atmosphere, the exploitation of space was still limited in concept and extent by the very high cost of putting payloads into orbit, and by the inaccessibility of space equipment once it had been launched. He forecast that the next important step would be the development "of an economical launch vehicle for shuttling between Earth and the orbiting space stations that soon will be operating in space."

The orbital workshop, to be launched by NASA in the early 1970s, was the progenitor of space stations that would be used for many scientific, technological and commercial experiments and processes. They would provide the facilities to study and understand the nature of space and would enable observatories to view the Sun, the planets and the stars beyond, to be placed outside the atmospheric veil of Earth. Stations

in orbit would serve as bases for continuous observation of the Earth and its atmosphere on a routine basis—for meteorological and oceanographic uses, for Earth resources data gathering and evaluation, for communications and broadcasting and for air, sea and ground traffic control. As these stations evolve, other uses would undoubtedly include the manufacture of specialised items utilising the unique characteristics of the space environment.

One of the applications for these stations that has intrigued planners for many years, Dr Mueller said, had been as fuel and supply bases, and as transfer points *en route* to high or distant orbits, to lunar distance, or toward the planets. The orbit of such a transfer station would normally be of low inclination and low altitude for reasons of economy, safety, convenience and flexibility.

As an example there could be operations between a close Earth orbit and synchronous orbit. A continuous-broadcast satellite could be installed, checked-out and, at a later time, maintained by service crews returning to the space station in low orbit. Or a spacecraft, fitted for lunar operations, could take on fuel and other supplies from the low, Earth-orbiting space station.

Essential to the continuous operation of such a station will be the ability to re-supply expendables as well as to change and/or augment crews and laboratory equipment. A basic consideration is the relationship between the original cost of the space station and the costs accumulated by re-supply support operations.

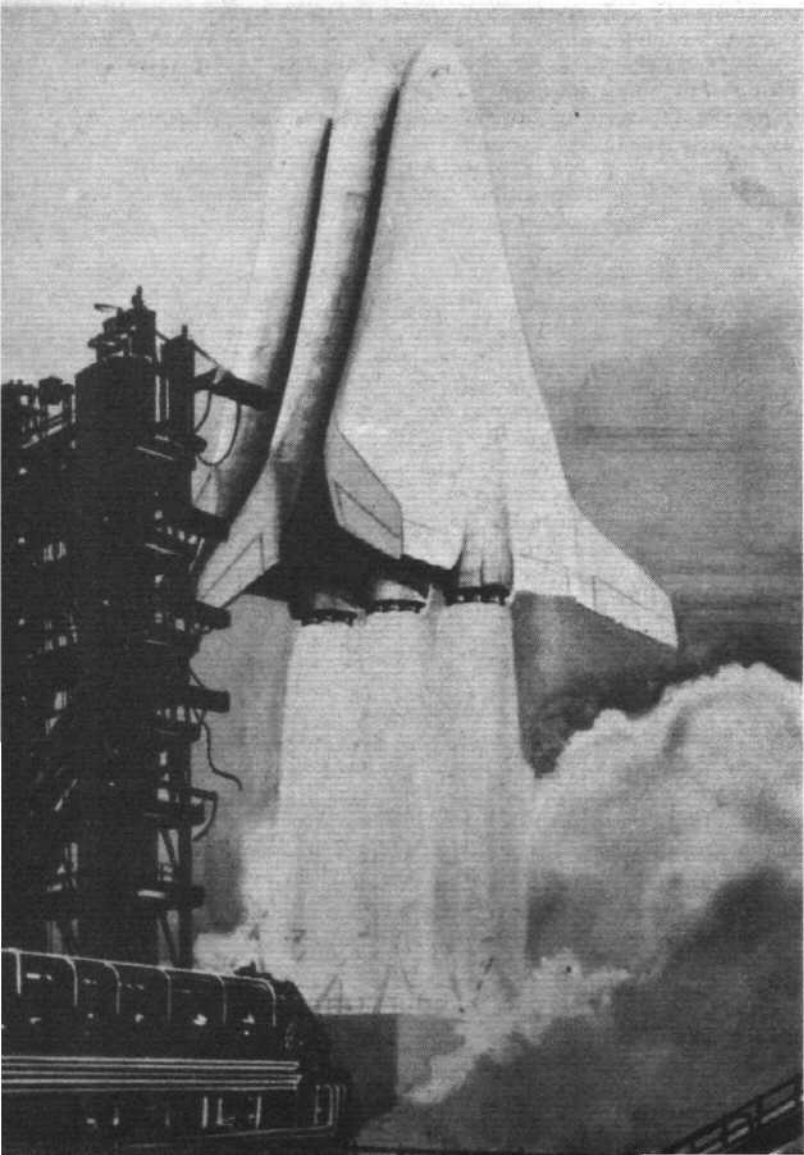
Dr Mueller said that studies had shown that, using today's hardware, the re-supply cost for a single, three-man orbital space station for a year equals the original cost of the space station. This had led NASA to carefully evaluate concepts for more efficient re-supply systems. Manufacture in space, fuel and supply storage for deep space operations, life support for crews on board space stations, required not tons, but thousands of tons of material to be shuttled to and from space.

Spaceflight

Therefore there was a real requirement for an efficient Earth-to-orbit transportation system—an economical "space shuttle." The elements to which one must look for cost reductions, he suggested, were aircraft-manufacturing techniques, aircraft development test procedures, maximum flexibility for multiple use and volume production, long-life components for repetitive re-use, and airline maintenance and handling procedures for economy of operation. The ideal would be for the "space shuttle" (similar to that illustrated in the heading impression) to operate in a mode similar to that of large commercial air transports and be compatible with the environment of major airports.

A promising design for the "space shuttle"—extrapolated by NASA from a number of proposals—takes the form of an outsize lifting-body to which are attached large drop tanks. This 1½-stage vehicle would take off vertically from a small pad at an airbase or major airport and upon returning from orbit would re-enter the atmosphere and glide to a runway landing with practically no noise. The landing would be completely automatic, with prime dependence upon the space-craft guidance system but with ground control back-up.

While a break-through in the development of aerodynamic space vehicles by NASA now appears very likely, Britain has also made detailed studies of such vehicles. BAC's Project Mustard was a design study for a space transporter (see "Flight," March 24, 1966) which would deliver a 3,000kg payload to a 300 n.m. polar orbit for a take-off weight of 936,000lb. The motors of the three nested stages all burn for take-off, the tanks of the orbital stage being kept topped-up from the two, non-orbiting boosters. In one respect (the salvage of boosters), Mustard appears to be more economic than the NASA design, in which, apparently, no provision is made for the salvage of the tanks.



Cryogenic tank trucks containing liquid oxygen and liquid hydrogen would refuel the craft on its pad. Seven years of accident-free experience in handling cryogenic fuels, Dr Mueller said, had advanced this technology to practicable safety. These non-toxic fuels were ten times more powerful than gasoline and had demonstrated their efficiency. He envisaged the cockpit of the space shuttle as similar to that of the large intercontinental jet aircraft, containing all instrumentation essential to complete on-board checkout. Programmable automated equipment would perform the systems and sub-systems tests necessary for take-off and flight support, and malfunction detection would be automatic.

The same basic design could also be applied to terrestrial point-to-point transport in military, commercial or cargo service. Its safety and comfort standards could be comparable to those of large jet transports.

The economics of the space shuttle, Dr Mueller continued, must be evaluated in comparison with today's means of accomplishing similar missions. Until now it had been essential to optimise space transportation systems on the basis of performance.

Only a decade ago technology was pushed to its limits in order to achieve barely orbital flight. Our first Vanguards and Explorers cost in the order of \$1,000,000 per pound of payload to fly into space. Saturn 5 delivers payload at a cost roughly three orders of magnitude less than Explorer 1. Given the will to accomplish the task we could reasonably expect a cost reduction of at least another order of magnitude by fairly conventional techniques. If, however, development of a space shuttle were implemented, cost might be reduced by two orders of magnitude. Any significant technological breakthrough in such areas as propulsion and structures would accelerate this process.

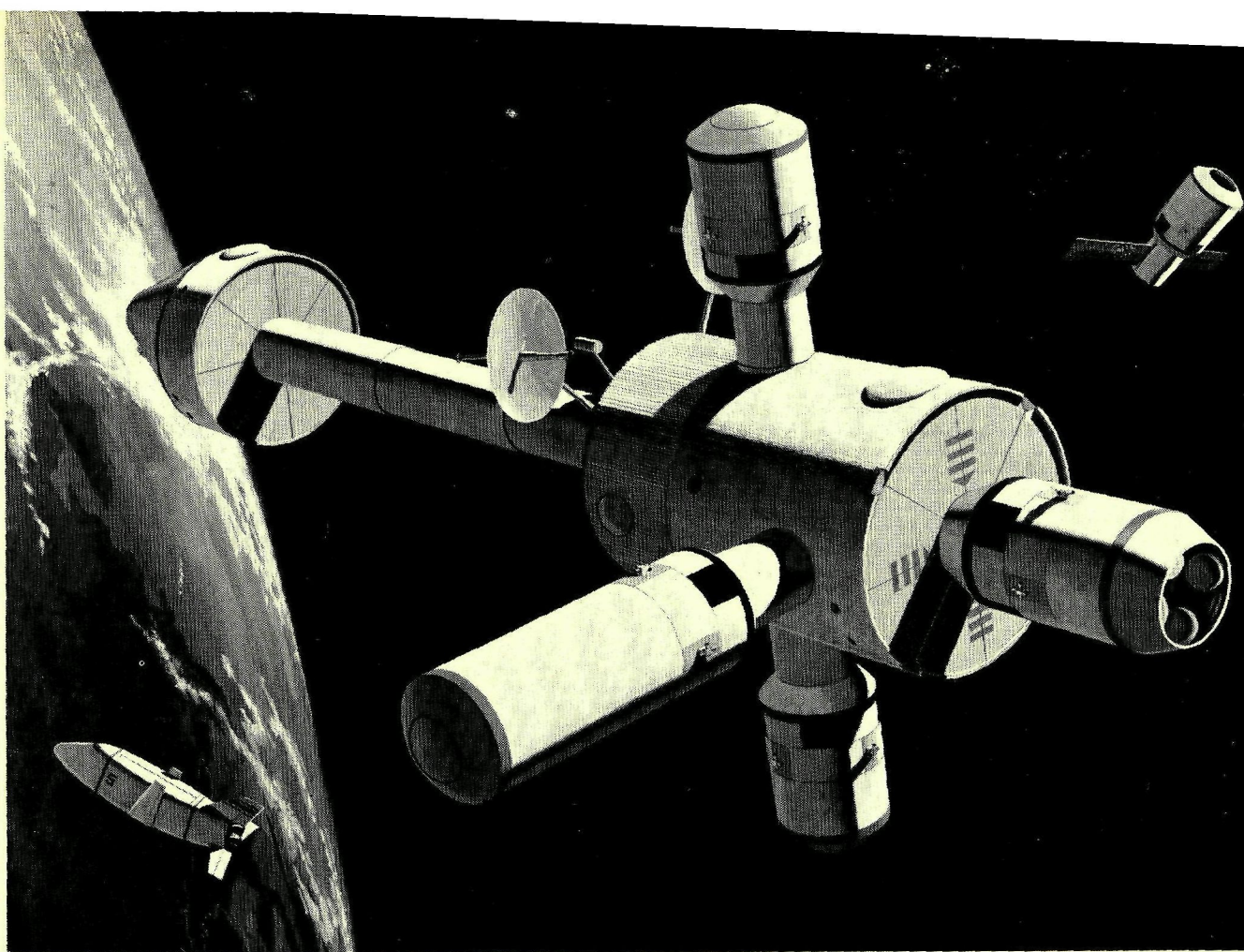
The proposed lifting-body booster, weighing some 600,000lb at lift-off, consists of a core vehicle—which contains all the required functional elements for boost and subsequent re-entry—plus external propellant tanks. Lift-off thrust would be about 750,000lb. The vehicle core, designed for vertical take-off and horizontal landing, contains all the high-cost equipment including the high chamber-pressure lox/hydrogen engines. Attached to the sides of the core are large inexpensively manufactured expendable tanks which carry the major part of the fuel required for boost. These are jettisoned when empty. The remainder of the boost increment required to attain orbital velocity, orbital manoeuvres and retro-rocket braking, is supplied by propellant tanks located within the core. It is estimated that a payload of some 25,000lb could be placed into orbit at 100 n.m. altitude.

Boost-glide applications

A vehicle of this kind is "technologically within the state of the art" and structure and drop-tank models are already undergoing test in NASA wind tunnels. Heat shield materials able to withstand between 20 and 25 re-entries are also being tested and sub-systems either exist or are under study. But a space shuttle development programme, if started now, could not be brought to fruition before the end of the 1970s. Significantly, Dr Mueller thought the need for such a transportation system will exist before then if, as is likely, the United States continues an active space programme. "Already we know that space station crews will need to be recycled at regular intervals. Communications, navigation and Earth sensing satellites, will probably require maintenance and/or refit."

Many new opportunities, he said, would exist for expanding Earth technologies once equipment could be moved into space laboratories. With the reduction in transportation costs now possible, many new uses for the space environment could be foreseen; for example, manufacturing in space is being seriously considered because of the unique zero-gravity conditions which exist in orbit. Here, molecular forces, which have little or no role in Earth-based manufacture, may become controlling factors in orbital processes. Surface tension and capillary forces, for instance, can be made to dominate processes in the zero-g environment.

Examples of zero-gravity manufacturing processes, said the speaker, were now absorbing the attention of some of our



Base in space

Preliminary designs for Nasa's permanent orbital space station, due for launch in the latter part of this decade, were submitted last year by McDonnell Douglas and North American Rockwell. In the first part of his article, D. BAKER* examines the MD proposal.

AS A LONG-LASTING, GENERAL-PURPOSE FACILITY in Earth orbit, [Nasa's] space station will be used to provide means of surveying Earth resources as well as to support the sciences of astronomy, astrophysics, aerospace medicine, biology, material processing, and space physics. The space station will also play a major role in the development of future space systems and operations, including space manufacturing. Its design, therefore, is dominated by the need to accommodate a broad spectrum of activities that may change markedly over the years. Thus, versatility is the design keynote—versatility and maximum exploitation of man's adaptability and talent for decision-making."

So begins the document presented to Nasa by the McDonnell Douglas Astronautics Company summarising the work undertaken during a \$2.9 million, 11-month, Phase B study for space station definition. A similar contract was issued, in July 1969, to the Space Division of North American Rockwell, and the two teams, the former headed by the Marshall Space Flight Centre, the latter by the Manned Spacecraft Centre, presented their documentation to Nasa last August.

Nasa in-house studies had generated certain criteria that were written into the contracts and continually amended and revised. Fundamentally, the station must support a

* Manned space flight consultant.

Heading picture The MD concept of the orbital station shown surrounded by attached and free-flying experiment modules and with the artificial-gravity boom extended. A shuttle pulls away following a support visit

viable and expanding experiment programme, be capable of using the shuttle as supporting transport, and yet must remain within the confines of present technology. From government/industry discussions came a list of constraints requiring the station to conform with facilities, launch vehicles, and operational techniques predicted to be available when the station would first become operational in 1977.

It was decided that the principle sizing constraint was that of the launch vehicle—a two-stage Saturn V, designated Int-21 and capable of lifting 195,000lb, 88,450kg into a 235 n.m., 435km orbit. The 33ft, 10m diameter of the second stage determined the outer circumference of the station. Pressurisation would be mixed oxygen/nitrogen at 14.7lb/sq in absolute, about 1kg/cm². In the event of an environmental failure in one section it would be necessary to provide a habitable environment for the 12 crew members while awaiting rescue.

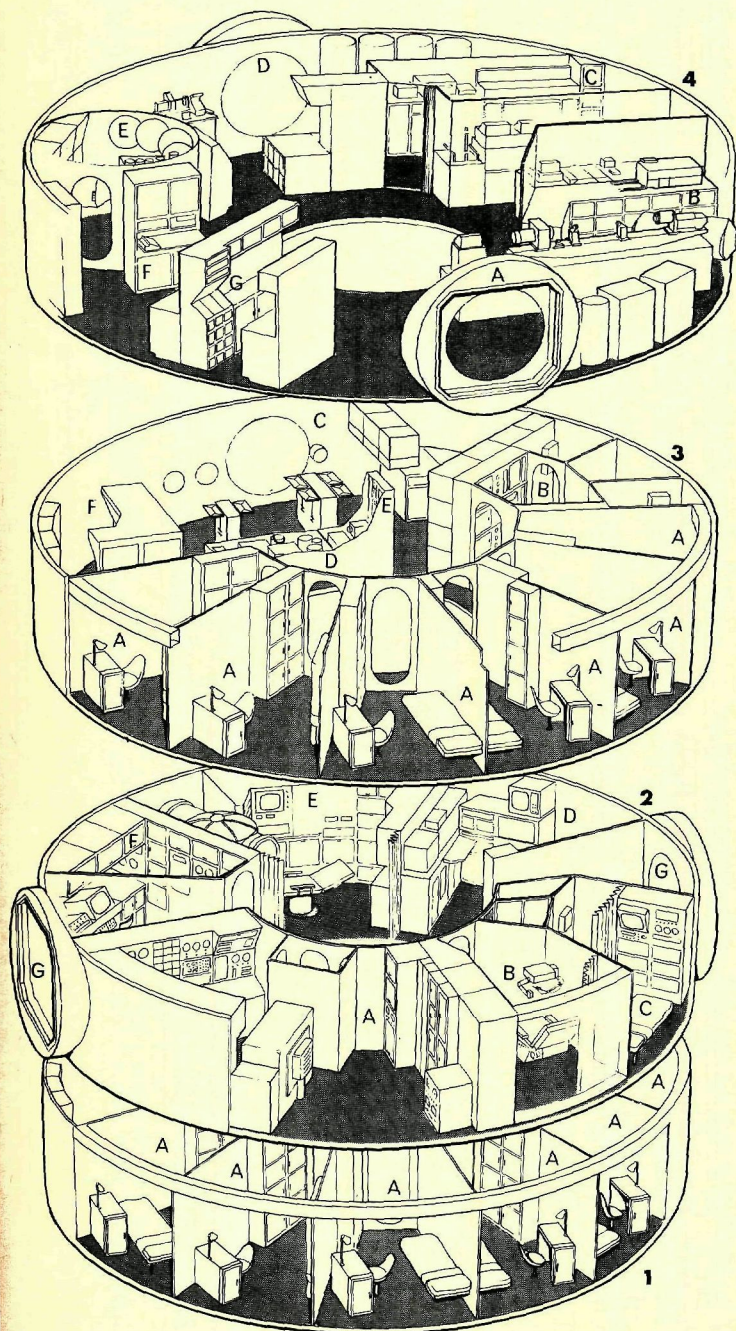
An important aspect of the experiment programme dictated the use of several modules either attached to the station or free-flying nearby. The docking ports on the

BASE IN SPACE...

station would provide a means of access to the pressurised attached modules, or enable the bulk transfer of cargo to integral experiments or subsystems to be performed in a shirt-sleeve environment. Finally, it should be possible to modify existing ground-support and assembly facilities for the project, and to minimise the need for mission support.

With these guidelines and constraints in mind the two

Deck arrangements, MD concept. Decks 1 and 3: **A** crew staterooms; **B** hygiene compartment; **C** wardroom; **D** Electrical control system; **E** electrical distribution; **F** control centre. Deck 2: **A** bioscience lab; **B** dispensary; **C** isolation ward; **D** data evaluation lab; **E** biomedical lab; **F** man-system integration lab; **G** docking ports (2). Deck 4: **A** docking port for fluid physics modules and cosmic ray physics; **B** optics facility; **C** hard-data process facility; **D** docking port for astronomy modules; **E** experiment and test isolation facility; **F** mechanical laboratory; **G** electronics/electrical laboratory



teams proceeded to analyse a wide range of possible concepts and design configurations. The results of their studies provide the most definitive insight yet into how the space station of the late 1970s will look and operate, and how it can best serve the requirements of the post-Apollo programme.

The McDonnell Douglas proposal

Before serious design of the space station could proceed it was necessary to define a viable experiment programme. A total of 27 experiments or functional programme elements (FPEs) was studied to determine which could be accommodated within the station itself. These integral experiments would be supplemented by a series of attached and free-flying modules containing those FPEs that were either too bulky or too heavy to be incorporated into the station design.

The core module of the MD proposal consists of two twin-common modules housing living quarters and experiment decks. A central tunnel runs the entire length of the core module, leading to a toroidal enclosure on the forward end. In the expanded-capability station, a third common module is attached to an extendible boom, increasing the scope for potential experiments.

The central tunnel, 10ft, 3m in diameter, is the main traffic artery for cargo and inter-deck passage. Access is gained through 5ft, 1.5m openings on each deck level and at the forward and aft ends from experiment or cargo modules. It serves as an escape path for the crew in the event of depressurisation of the upper or lower common modules, and acts as a main structural tie.

The station is arranged with Deck 1 at the aft end and Decks 5 and 6 in the third common module, called the artificial-gravity module. Extension of the boom structure separates this assembly from the core module and permits long-term artificial gravity to be induced by rotation about the centre of gravity.

The four-deck core module itself consists of 33ft, 10m diameter cylindrical sections serving as the principal load-carrying members during boost, and stressed to withstand the 14.7lb 16/sq in environment during orbital operations. The aluminium alloy sides, 4.5in, 11.4cm thick, interface with the titanium isolation skirt shrouding the forward equipment areas. Circumferential frames around the core module contain radiator tubes which serve to support the outer meteoroid shield. This double-bumper configuration provides a 0.99 per cent probability of no meteoroid penetration in ten years of operation.

The three common modules each contain one deck for crew habitation and one deck for experiments. Deck 1 contains six crew quarters, each fitted with a bunk, personal desk and locker facilities. Also on this deck, a multi-purpose wardroom serves as canteen, recreation and exercise area, with provision for conferences with tables and equipment stowed. A suitably screened galley area lies adjacent to the wardroom, with hot and cold water, refrigeration and cooking facilities. A hygiene unit enables the crew to retain individual privacy while washing, showering or using the toilets. The control centre, located between the commander's stateroom and the wardroom, can be adapted to fill the unique requirements of each common module. A single, 5ft docking port affords access from a cargo module to the interior of the deck area.

Deck 2 is principally dedicated to experiment equipment and support apparatus. In the current configuration a biomedical and bioscience laboratory provides facilities for research on vertebrates, invertebrates, plants and micro-organisms. A dispensary and isolation ward also provide facilities for medical experiments. Two docking ports are provided for transfer of experiment equipment or supplies.

Together, Decks 1 and 2 form the lower common module and are separated from Deck 3 by a pressure bulkhead stressed with radial beams attached to the central tunnel.

Deck 3 is identical to Deck 1 and contains all the necessary accommodation for the remaining six crew members. The general-purpose laboratory located on Deck 4 contains optical electronics, test, isolation and data

BASE IN SPACE . . .

facilities. An airlock is provided for selected engineering experiments. Two docking ports provide for the attachment of experiments requiring a high level of station support (i.e., fluid physics, cosmic-ray physics, astronomy modules, etc. Access to the normally unpressurised forward equipment area is gained through the tunnel.

Decks 5 and 6 comprise the optional third common module located above the upper conical equipment area. Cylindrical extrusions to the vertical side-walls of the core module support the artificial-gravity module for launch. If prolonged periods of artificial gravity are required, the telescoping boom attached to the top of the central tunnel extends this module some 120ft, 36.5m beyond the four-deck core module.

Deck 5 contains two separate centrifuge systems, one located above the other, for man and specimen evaluation. Deck 6 is available, after the period of artificial gravity, for additional experiment use and is particularly suitable for primate and life-cell studies.

The 10ft central tunnel carries all the electrical and environmental lines to each deck and provides stowage for food lockers, film vaults, and short-period living accommodation during emergencies. It would be particularly useful for its added shielding from dangerous solar flares.

In the launch configuration the station and artificial gravity module is 111ft, 34m long and weighs 187,000lb, 84,800kg. With the module deployed the configuration extends to more than 200ft, 61m.

Systems concepts

In keeping with the philosophy of using existing technology, the station systems provide an important carry-through from advanced research projects and are designed to incorporate many off-the-shelf items.

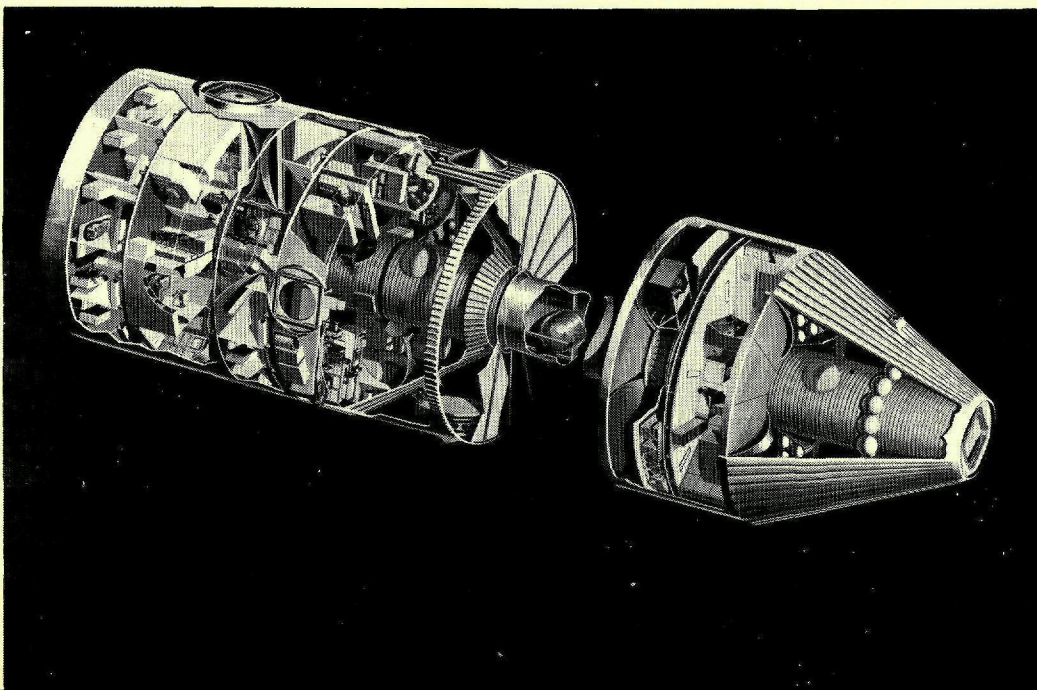
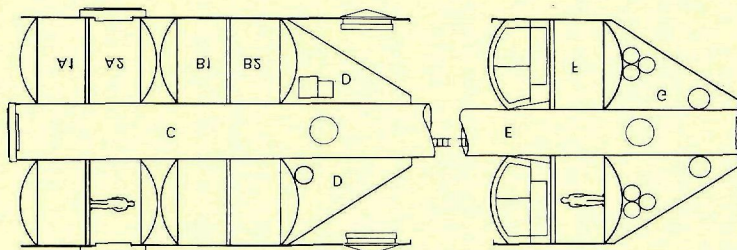
The total electrical power requirements of the station

have been assessed at a maximum of 25kW, realised when a 24-man overlap crew is on board. To match this, McDonnell Douglas subcontracted studies to develop the concepts of the isotope/Brayton system. Two assemblies are installed in the unpressurised forward section of the core module, supplying 14.9kW each, with a third unit located in the forward area of the artificial-gravity module. Each source consists of 52kWt (thermal kiloWatts) of plutonium 238, a Brayton-cycle conversion system, shielding, and a control assembly to maintain a uniform turbine-alternator-compressor speed. The 1,200Hz, 115/200V a.c. power supply is supplemented during periods of peak demand by seven nickel-cadmium batteries. A unique feature of the concept is the use of a manipulator system and remote TV cameras for rotating the Brayton unit 180° and dumping heat loads to space.

The environmental control system is designed to supply a 14.7lb/sq in oxygen/nitrogen atmosphere to all three common modules and the tunnel area. The three systems serve the three common modules, with the tunnel referenced to either one. Electrolysis and Sabatier reaction precesses provide partial recovery of the expended oxygen. Full water recovery is achieved by air evaporation and reverse osmosis, supplemented by CO₂ conversion in the Sabatier unit. Methane, also produced as a by-product of the Sabatier reactors, is used in the reaction control system for orbit-keeping duties. Two 180° radiator segments, an integral part of the meteoroid shield, reject the heat generated by the environmental control system.

Control and stabilisation is achieved by six control-moment gyros and clusters of 50lb, 0.222kN and 0.025lb, 0.111N-thrust reaction control engines. The gyros are situated in the interior of the central tunnel, in line with the bulkhead dividing the two principal core modules. On-board navigation is achieved with a sextant and telescope unit slaved to an inertial reference system. In this way, the station can operate in a completely autonomous mode, fitting it ideally for lunar orbit or transplanetary roles.

To be continued



General plan, MD concept. **A1, A2** module A, Decks 1 and 2; **B1, B2** module B, Decks 3 and 4; **C** central tunnel; **D** subsystem equipment bay; **E** extendible booms/tunnel; **F** artificial-gravity module; **G** equipment bay

Structure

Advanced composite and metallic structures will reduce weight. Automated fibre placement and friction-stir welding will simplify assembly. Ultimately sensors and actuators will be integrated with the structure to enable adaptive "morphing", or shape changing.

Flightdeck

Digital flights controls will become increasingly "intelligent", enabled by fly-by-light and power-by-wire. Broadband datalinks will network aircraft to aircraft and pilots to controllers. Integrated hazard sensors and synthetic vision will improve safety.

Aerodynamics

Active flow control will transform aerodynamics, reducing drag and increasing lift. Hybrid laminar flow control, adaptive shock "bumps", pulsed-jet separation control and flexible multi-function flaps will reduce cruise fuel consumption and cut airport noise.

Propulsion

Shaft-integrated generators will power all-electric aircraft systems, electric-driven accessories and oil-free magnetic bearings. Ultimately electric-driven engines, powered by hydrogen fuel-cells in the wing, will eliminate emissions.

Configuration

The quest for efficiency could lead to new configurations. The box wing is compact and lightweight and a possible interim step to the blended wing body, which is aerodynamically and structurally highly efficient but faces ground handling and passenger acceptance challenges.

But Boeing, after taking over McDonnell Douglas and reducing the USA to one commercial jetliner manufacturer, turned its back on the HSCT and NASA cancelled its high-speed research programme in 1999. Even after years of work, significant question marks remain over the environmental acceptability and economic viability of supersonic airliners. Research continues in Europe and the USA, but at a level far below that required to make a second-generation supersonic transport a reality any time soon.

So size and efficiency have won the latest round. They combine in the 550-seat A380, which Airbus calculates will burn 12% less fuel per passenger than a 747-400. The largest part of that saving comes from the latest generation of high-bypass turbofans, but the four-engined A380 also benefits from advances in fly-by-wire flight controls and composite primary structures.

The A380 will be the first airliner with a carbonfibre centre wing box, while the rear pressure bulkhead and everything aft will also be carbonfibre. A glassfibre/aluminium laminate, Glare, will be used for upper-fuselage panels, while the lower fuselage panels will be laser beam-welded aluminium. Airbus calculates the materials and structures advances in the A380, compared to the 747, will reduce weight by up to 15t while improving durability.

Electric actuation

Details of Boeing's 7E7 are still sketchy, but the 210- to 250-seat twinjet is expected to incorporate several of the technologies originally envisaged for the Sonic Cruiser. These include composite fuselage and wing structures, electric flight-control actuation, all-electric environmental control system and integrated vehicle health management. Boeing is projecting a 17% lower fuel burn per passenger than the Airbus A330, and a 10% lower operating cost,

with 80% of the savings coming from the engines, which will be new very-high bypass ratio (10:1) turbofans.

Airliners have production and operating lifespans of 20-30 years, so the conventionally configured A380 and 7E7 will be around for a long time. The A380 is scheduled to enter service in 2006 and the 7E7 in 2008 and could be flying well into the middle of this century. Proponents of unconventional configurations, like the blended wing body (BWB), will have to wait for the next generation of airliners – and possibly longer, as there is much that can be done to improve the efficiency of the traditional airliner layout.

Boeing may have ditched the sleek Sonic Cruiser in favour of the super-efficient 7E7, but its long-running BWB studies continue. The aerodynamically and structurally effi-

cient blended wing body is widely regarded as the most promising new configuration for an environmentally friendly airliner, although there are concerns over airport compatibility and passenger acceptance.

Work to date has concentrated on very

large airliners, with up to 1,000 seats, but Boeing's Phantom Works has schemed out a modular family of long-range airliners ranging in capacity from 200 passengers to 550.

NASA research suggests a 2015-time-frame BWB would be three times as fuel-efficient as a 747, and generate 10% of the NOx emissions. Boeing calculates that a 480-seat trijet BWB would be almost 20% lighter, and burn more than 30% less fuel per passenger, than the A380.

Boeing's latest work has also pushed up the cruise speed of the blended wing body, from the originally envisaged M0.85. Computational fluid-dynamics analysis indicates a cruise speed of M0.93 is feasible, but the "sweet spot" in terms of improved speed with minimal penalty is M0.9. In the eyes of the BWB's many proponents, this additional speed capability further improves the design's appeal.

The BWB's big advantage over conventional designs is that, as a spanloader, the configuration is extremely efficient. There are aerodynamic and structural challenges to be overcome, mainly involving aeroelasticity and flight control, but the biggest barrier to development is market demand. While there remains room to improve the efficiency of traditional configurations, there is little incentive to pursue unconventional designs.

The incentive could yet come in the

There is room to improve efficiency of traditional designs, but little incentive to pursue unconventional configurations



JET PROPELLED FLYING WINGS

Consideration of a Large Air Liner for High-speed Operation at Altitude

SOME day the flying wing will emerge as the accepted form of a passenger air liner. There are so many advantages in accommodating the passengers in the section of the wing and at the same time enclosing the power units to permit a clean aerodynamic structure free from protuberances, that its eventual advent seems assured. The total drag is reduced by some 33½ per cent. as compared with a normal type of aircraft, and new impetus is given to the problem by reason of the gradual perfection of the gas turbine of low weight operating either as a pure jet or driving airscrews. When the successful flying wing air liner appears, it will almost certainly be propelled by gas turbines.

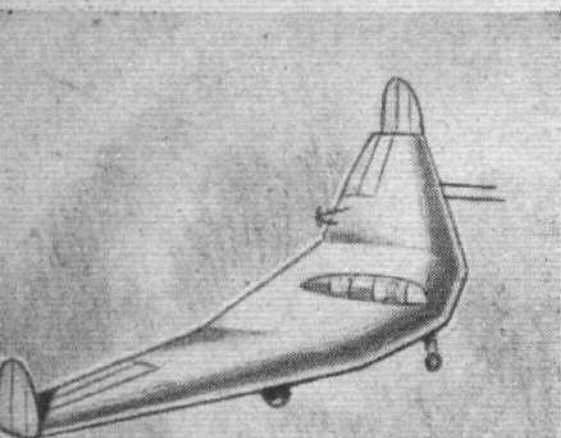
But the time is not yet. Many problems face the designer, not the least of which is stability and effective control in the three axes—longitudinal, lateral and directional—due to what is termed absence of lever arm suspension and the large size necessary for successful commercial operation. When gas turbine development reached the important stage it did in 1944, new consideration was at once given to the flying wing as turbines offered such an ideal form of compact power unit of low specific weight for an aircraft structure so appealing in theory. For years designers have seriously considered the idea and a number of small examples of flying wings have been produced and flown under power, or as gliders. Northrop in America is responsible for several specimens and in Britain the Handley Page Manx tailless type with two Gipsy engines, and more recently the Armstrong Whitworth AW52, first as a glider and now with twin Nene turbine-jets, will be recalled.

German scientists have worked on the problem since 1910 when Junkers patented the *Tragflächen* (literally carrying surface), a thick-wing aircraft with submerged engines. Since then notable designs have been advanced by Lippisch, and during the 1939-45 war by Horten (see "Gas Turbines and Jet Propulsion for Aircraft").

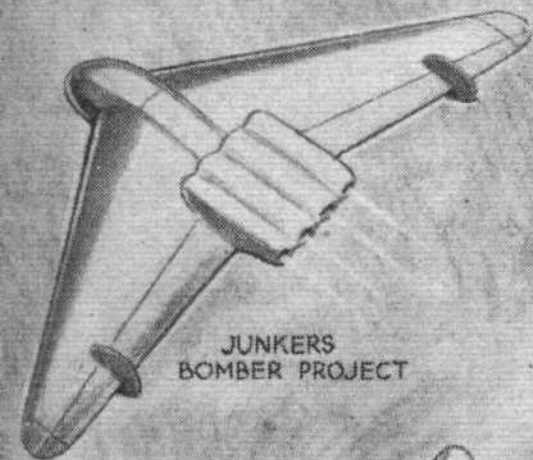
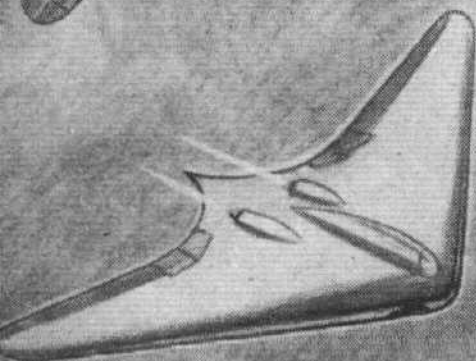
Efficient in Large Sizes

Although highly efficient structurally, the "all wing" design must be evolved in a large size to be efficient as a passenger or load transport, because the ratio of surface to volume is large and head room liable to be restricted. Consequently the flying wing, when it arrives as a commercial proposition will be big, with an all-up weight of say 300,000 lb., as at that size the wing will accommodate a 15 per cent. stowed load, or as much as a fuselage.

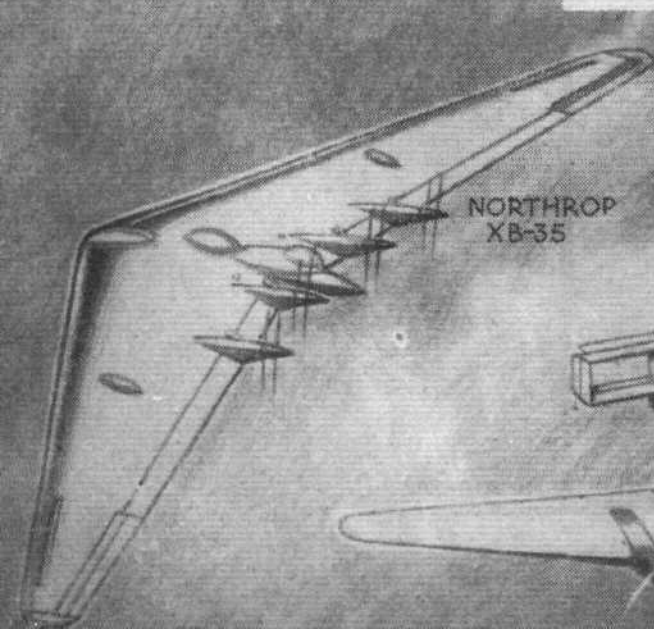
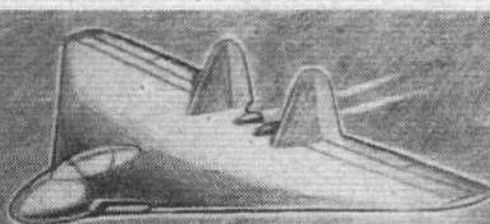
As a peep into the future, a suggested form of flying wing air liner propelled by four large gas turbines is the subject of the accompanying drawing. It is a companion picture to the tailless spearhead design with thin wings, proffered in *Flight* of November 7th, 1946. Modern tendencies have been embodied in this all-wing design of some 200ft span, with a maximum chord of 50ft. Intended as a 500 m.p.h. liner for operation at high altitudes, it has a pressure cabin and control of the boundary layer of air by the incorporation of the suction-type or cusped aerofoil top



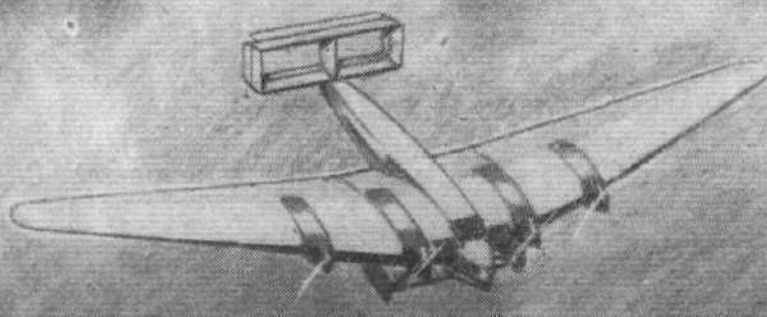
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JUNKERS
BOMBER PROJECT

HORTEN IX

NORTHROP
XB-35

LIPPISCH P.II PROJECT



A.W. 52

